A Survey to Model Demand for an Air Taxi Airport Shuttle

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A SURVEY TO MODEL DEMAND FOR AN AIR TAXI AIRPORT SHUTTLE

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LIST OF SYMBOLS AND ABBREVIATIONS

AAM	Advanced air mobility
AIAA	American Institute of Aeronautics and Astronautics
AV	Autonomous vehicle
CAV	Connected and autonomous vehicle
COVID	Coronavirus disease
CSA	Combined Statistical Area
EV	Electric vehicle
eVTOL	Electric take-off and landing
FAA	Federal Aviation Administration
GDP	Gross domestic product
IRB	Institutional Research Board
ODAS	On-demand air service
PAV	Passenger air vehicle
SAV	Shared autonomous vehicle
UAM	Urban air mobility

SUMMARY

In this paper, I present details of a survey designed to estimate air travelers' willingness to pay for electric vertical take-off and landing (eVTOL) flights in urban areas in the United States for the purpose of traveling from home to a commercial airport. The survey will be administered in January 2021 and responses will be obtained from 2,800 individuals who had taken at least two roundtrips by air in 2019 (before the COVID-19 pandemic), who had annual household incomes of at least $75K, and who resided in the Atlanta, Boston, Chicago, Dallas-Ft. Worth, New York City, San Francisco Bay Area, or Los Angeles Combined Statistical Areas (CSAs). A stratified sample will be used to ensure a minimum number of responses for different household income brackets, pre-COVID air travel frequencies, and trip purposes (reimbursed business trips and self-paid leisure trips).

Respondents will answer questions related to their opinions about travel and air travel, their current travel behavior, their most recent air trip, and their opinions about self-driving cars and air taxis. Respondents will then answer a series of trade-off questions. For these questions, respondents are presented with scenarios in which they must choose between three travel mode options for a hypothetical airport trip based on characteristics like cost and travel time. The survey concludes with questions related to the respondent's lifestyle and attitudes, his or her use of technology, and his or her socio-economic characteristics.

This thesis complements the other contributions I have made during my master's degree program and serves as the only known survey instrument used to study demand for an air taxi airport shuttle service.

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

With the latest advancements in battery technology, efforts have been made to incorporate electric propulsion into small aircraft. At the same time, ground transportation technology has been advancing at a rapid rate through the introduction and development of electric vehicles (EVs), ride-sharing technologies, and connected and autonomous vehicles (CAVs). Urban air mobility (UAM), also referred to as advanced air mobility (AAM)[1], serves as the intersection between the newest aircraft technology and urban transportation systems. UAM aims to use small-scale aircraft to link individuals and cargo between and within urban areas by taking advantage of the air space. UAM includes existing technologies, such as helicopters and drones, but it also includes a newer mode that is currently in testing and preliminary stages of development: the electric vertical take-off-and-landing (eVTOL) aircraft, also referred to as the air taxi. For passenger travel, the eVTOL aircraft provides advantages unique from any existing modes. These aircraft may allow for on-demand services, similar to Uber and Lyft, using aircraft that carry between 2 and 4 passengers, but they would take advantage of air space rather than crowded city streets. These aircraft are also quieter and use a cleaner fuel source than helicopters, which offer similar existing services, like Blade and Uber Copter. These on-demand services that

[1] On March 23, 2020, the U.S. National Aeronautics and Space Administration (NASA) began referring to its on-demand aerial activities as AAM instead of UAM to reflect a more inclusive vision for both urban and rural applications (NASA, 2020). We will use UAM throughout the paper.

may be possible with eVTOL aircraft could serve a variety of purposes including commuting, first response services, long-distance intercity trips, and trips to the airport.

UAM is an up-and-coming field, which means there is plenty of space for new research. The aerospace side of research, which tends to focus on topics like aircraft technology, air traffic management, and aviation operations, has significantly ramped up UAM/air taxi research in recent years. However, the transportation side of UAM research is still catching up. Transportation research, coupled with aerospace research, will be vital to determining the feasibility and implementation steps of an eVTOL service. In particular, examining potential demand for such a service has become a key area of focus within the transportation side of UAM research. While prior work has been completed with a focus on commute trips, one of the gaps in research seems to be examining demand for an air taxi airport shuttle service (Booz Allen Hamilton, 2018; Thompson, 2018; Fu, Rothfeld, and Antoniou, 2019; Song, Hess and Decker, 2019; Binder et al., 2018; Garrow et al., 2019). For example, at least four major studies have noted airport shuttle service as a potential first use case for UAM (Thompson, 2018; Mayor and Anderson, 2019; Johnson, Riedel, and Sahdev, 2020; Booz Allen Hamilton, 2018). With my thesis, I aim to begin filling that void by designing a survey of air travelers residing in seven urban areas in the United States, which will be used to predict the level of demand for an air taxi airport shuttle service among different types of people. The design of this survey will be detailed in Chapter 3 and will be submitted in 2021 as a paper for the June 2021 American Institute of Aeronautics and Astronautics (AIAA) conference. Chapter 4 will then contain conclusions and detail future research opportunities within this subject.

1.2 My Prior Contributions

During my master's degree program, I co-authored three papers related to UAM (not including the AIAA paper that forms the basis of my thesis). The first paper I was involved with is titled "A Multi-Commodity Network Flow Approach for Optimal Flight Schedules for an Airport Shuttle Air Taxi Service" and was featured in conference proceedings for the AIAA Scitech 2020 Forum (Roy et al., 2020b). This paper developed the case-study-based framework for an air taxi airport shuttle dispatch model by using estimations of trip generation, value of time assumptions, flight performance modeling, and network optimization. My role for this paper was primarily related to developing the demand model. To do this, I used an existing airport trip generation model, developed by the region's metropolitan planning organization, combined with data from the federal aviation administration regarding departure and arrival times of flights at the region's airport. These data helped provide a high-level estimate of the total number of trips taken to the airport and at what times these trips are likely to occur. From there, assumptions related to values of time and other inputs were used to estimate demand for an air taxi service to and from the airport. Then, aircraft characteristics, flight times, and theoretical vertiport placements were used to develop an optimal flight schedule for the dispatch of an eVTOL aircraft on a sample day. This paper used several assumptions, but it set the groundwork for future research to be done once these assumptions can be refined. My thesis will be the first step in refining the assumptions made in developing a demand model for this type of service.

The second paper I co-authored is titled "Market Segmentation of an Electric Vertical Take-off and Landing (eVTOL) Air Taxi Commuting Service in Five Large U.S.

Cities" and is currently under review for its inclusion in *Transportation Research Part A* (Garrow et al., 2020b). This study used results from a stated preference survey of high-income commuters in five U.S. cities to conduct factor and cluster analysis and examine which characteristics influenced positive interest in eVTOL air taxis. My role in this paper consisted primarily of adding to the literature review. I focused on looking into research related to adopting new modes of transportation, like ride-hailing, carsharing, electric vehicles and autonomous vehicles. Findings were similar among different studies. Early adopters of new modes tended to be younger, high-income, and highly educated individuals (e.g., see Dong, DiScenna, and Guerra, 2019; Hudson, Orviska, and Hunady, 2019; Kopp, Gerike, and Axhausen, 2015; Liu et al., 2019; Potoglou et al., 2020; Spurlock et al., 2019; Vij et al., 2020; Wang and Zhao, 2019). These characteristics also ended up characterizing individuals with more enthusiasm for eVTOL aircraft according to the results of the survey in this study. Studies in the literature review also found that characteristics such as an individuals' trust in technology and willingness to travel with strangers heavily influenced their enthusiasm toward new and shared modes of transportation (Merat, Madigan, and Nordhoff, 2016; Choi and Ji, 2015; Nielsen et al., 2015; Lavieri and Bhat, 2019). The study concluded that traditional mean-centered factor scoring results in an understatement of the level of enthusiasm for eVTOL air taxis and further suggests the use of non-mean-centered factor scoring approach for this type of data (Garrow et al., 2020b). After conducting the survey designed in Chapter 3, it will be interesting to compare the results for an airport shuttle air taxi survey to this air taxi commute survey's results. When analyzing the results, it may be beneficial to use non-mean-centered factor scoring, as this study suggests.

The third paper I co-authored, which is my most significant contribution to date, is titled “Urban Air Mobility: A Comprehensive Review and Comparative Analysis with Autonomous and Electric Ground Transportation” and is currently under review for its inclusion in a special edition on urban air mobility in *Transportation Research Part C* (Garrow, German, and Leonard, 2020). Relevant findings from this paper are included in Chapter 2 of this thesis. This paper involved conducting a thorough search of transportation journals and aerospace journals for articles about or related to UAM, eVTOL technologies, electric vehicles, and autonomous vehicles, resulting in an excel database of about 800 different articles. The paper synthesizes the main findings from these articles to inform future UAM research directions. My role in this paper was to organize the database, which included almost 800 articles. This workbook will be included as a supplemental document when the article is ultimately published and enable researchers from across different fields to quickly identify patterns are relevant articles from the ground and air transportation fields, thereby facilitating more interdisciplinary research in UAM. I used the database to extract characteristics about the authors of these articles and the articles themselves. This included creating graphic flowcharts of keywords associated with each of the articles for the transportation literature and the aerospace literature. These keyword flowcharts led to the conclusion that UAM research in aerospace literature tends to focus on aircraft technologies and operations while EV and AV research in the transportation literature tends to focus on technology adoption and integration with existing infrastructure. Conducting a thorough search of relevant literature revealed the gaps in research in the UAM area; it revealed that little work has been done to investigate demand for an air taxi airport shuttle service. This is what ultimately led to the decision to design a survey for that purpose.

Having co-authored three air taxi papers during my time as a research assistant, I realized where my next contributions would make the most impact for my thesis. My coursework has also led me to the subject of this thesis. Specifically, taking discrete choice modeling and survey design courses helped me to gain unique skills related to designing and analyzing results from a mode choice survey. This paper will use insights gained from my coursework as well as past work done by myself and others to design a survey of air travelers for the purpose of predicting demand for an air taxi airport shuttle service in seven major U.S. cities.

1.3 Literature Review

Prior work has been done to assess the overall and commute-specific demand for eVTOL air taxis through focus groups and stated preference surveys. Garrow, German, and Ilbeigi (2018) conducted four focus groups to gain a high-level understanding of participants' willingness to pay for and travel in eVTOL aircraft. These focus groups found that "time-sensitive and high-value trips where avoiding traffic congestion" were most likely to attract demand for eVTOL trips (Garrow, German, and Ilbeigi, 2018). Binder et al. (2018) developed a survey of 2,500 commuters in five CSAs which was designed to help understand individuals' willingness to pay to use eVTOL aircraft for the purpose of commuting. A follow-up to this survey was designed for a similar purpose, but it extended the 2018 survey by incorporating trade-off questions used to predict competition among eVTOL aircraft, autonomous ground vehicles, and traditional ground vehicles for commuting purposes (Garrow et al., 2019). Peeta, Paz, and DeLaurentis (2008) conducted a short, stated preference survey to develop models predicting traveler propensity toward on-demand air service (ODAS). Respondents were asked based on different scenarios whether or not they would consider switching from their current mode to ODAS. The study found that "travel distance, service fare, and the ODAS location [are] key factors influencing user switching decisions" (Peeta, Paz, and DeLaurentis, 2008). This survey designed in this paper takes each of these factors into consideration when developing trade-off questions for mode choice.

Many of the air taxi surveys done previously focused on many different trip purposes at a high level or they focused in on commuting as the trip purpose of interest. A handful of studies have focused on determining demand for an airport shuttle service. These studies take into account a variety of inputs, sometimes including the results from a focus group or survey. Airbus conducted focus groups in New York City, Frankfurt, and Shanghai, finding that airport transfer was the "most important" UAM use case in all three cities (Thompson, 2018). Airbus predicts that in NYC, airport transfers could account for "more than half of the [air taxi] trips based on today's mobility patterns" (Thompson, 2018). The Booz Allen Hamilton team put together a thorough market study for urban air mobility in the U.S. (Booz Allen Hamilton, 2018). The study investigated a variety of focus markets for UAM, one of the main markets being an airport shuttle service. The team conducted focus groups and a survey to expand on topics specific to "willingness-to-fly, weather, and noise concerns" (Booz Allen Hamilton, 2018). The focus groups did not conclude anything specific to airport shuttles, but they did indicate "a strong preference for longer trips including intraregional trips in excess of one-hour driving time," a finding consistent among other studies which may serve as justification to prioritize cities with less central major airports and/or more ground traffic congestion (Booz Allen Hamilton, 2018). From their survey, the team found that respondents generally chose UAM over autonomous vehicles (AVs) or shared autonomous vehicles (SAVs) for trips to and from the airport when given only those three choices (Booz Allen Hamilton, 2018). The survey presented in this thesis would expand on this by incorporating two other additional mode choices into the trade-off questions: driving yourself and taking a ride-hailing service. This will combine current and future mode choices to provide a more accurate mode-choice model. Roy et al. (2020a) developed a discrete choice model focused on predicting mode choice for business travelers that may use an air taxi airport shuttle to travel to and from the airport. This model considered a variety of factors including drive time, aircraft characteristics, distances among existing infrastructure, and tract-level population and income distribution (Roy et al., 2020a). These factors combined with survey results would lead to a more robust mode-choice model.

For this study, seven Combined Statistical Areas (CSAs) have been chosen to survey: Atlanta-Athens-Sandy Springs, Boston-Worcester-Providence, Dallas-Ft. Worth, San Francisco Bay Area, Los Angeles-Long Beach, Chicago-Naperville, or New York City-Newark. Of the past studies that conducted city-specific analysis, some common factors were considered when picking which cities to study, and many past studies also focused on seven cities chosen for this study. The Booz Allen Hamilton UAM Market Study (2018) surveyed respondents from Houston, Los Angeles, New York, San Francisco, and Washington, D.C. When conducting other analysis, the study focused on five additional cities: Miami, Dallas-Ft. Worth, Denver, Phoenix, and Honolulu (Booz Allen Hamilton, 2018). Of the ten total cities analyzed in the study, four overlap with the chosen cities for this survey. The team describes the reasons for choosing each of these cities, including high willingness to pay, large number of edge cities, multi-airport model, high traffic congestion, and good available infrastructure (Booz Allen Hamilton, 2018). Many of these reasons cited align with the reasons similar cities are included in this study. NEXA's UAM Report included analysis of 74 cities worldwide, and all seven of the cities chosen for this survey were included in their analysis (NEXA Advisors, 2019). NEXA describes that it was important to study a variety of cities because each metropolitan area has unique "transportation issues, congestion, population density, airports, transportation infrastructure, regulation, business aviation, GDP, local politics, [and] per capita income" that affect the predicted level of demand for air taxis (NEXA Advisors, 2019). Roy et al. (2020a) studied five metropolitan areas: Los Angeles, New York City, Boston, Orlando, and Atlanta, and these cities were chosen based on "an analysis of business-class airport passenger throughput". Business traveler throughput was a consideration when choosing the seven CSAs for this survey, which explains the overlap between this study's focus cities and Roy et al.'s focus cities (Roy et al., 2020a).

1.4 Outline of Thesis

Given the relative lack of attention to understanding customer demand for an air taxi airport shuttle, this thesis designs a survey instrument and recruitment plan to collect data that can be used for this purpose. Before detailing the survey design, Chapter 2 includes a meta-analysis of existing UAM and transportation literature, specifically as it relates to demand modeling. Details in Chapter 2 are heavily drawn from one of the papers I co-authored (Garrow, German, and Leonard, 2020). Given the survey instrument and supporting details have been submitted for publication consideration in the AIAA Summer of 2021 conference, I use a "paper format" to this thesis and include the draft contents of the AIAA paper summarizing the survey design details. The AIAA paper includes the main manuscript and three accompanying appendices: one for the survey instrument, one that analyzes distances from residences to the nearest major airport for all of the metropolitan areas included in the study, and one for the levels included in the trade-off questions. These materials are included in the thesis as Chapter 3 (main body of the manuscript), Appendix A (survey instrument), and Appendix B (supporting frequency charts of distances to major airports). The levels to be included in the trade-off questions are pending approval from the project sponsor, so that appendix has been omitted from the thesis and will be included in the AIAA paper when finalized. However, Appendix C in this thesis includes the trade-off question blocks for an example scenario using the preliminary levels. Chapter 4 then includes conclusions and suggestions for future research related to the work in the thesis.

1.5 Thesis Contributions

There are two major contributions of my thesis. First, as part of this thesis, I designed one – if not the first – survey instrument to study demand for an air taxi airport shuttle. The data collection, which will occur after the thesis is submitted in Spring of 2021, will provide some of the first insights related to how UAM adoption varies by trip purpose, party size, and airport parking costs. I hypothesize that compared to conventional auto, ride-hailing will be more competitive for shorter-distance trips, air taxi will be more competitive for longer-distance trips, and that very few self-paid leisure trips with three or more travelers will consider an air taxi. I also hypothesize that the timing of adoption of air taxis and AVs will be related to the "straight-lining" phenomena observed in prior commuter surveys where a non-trivial percentage of respondents never chose air taxi as an option across eight trade-off questions. Second, as part of the design of these trade-off questions, I was responsible for learning how to use Ngene, a software for generating trade-off designs (ChoiceMetrics, 2018). The use of this software allowed me to leverage results from prior commuter surveys to design the trade-off questions in a way that is “smarter” - meaning the combinations of levels and trade-off questions shown to respondents is more closely tied to expected parameter estimates, which in theory provides a more efficient design.

CHAPTER 2. A META-ANALYSIS OF RESEARCH IN URBAN AIR MOBILITY, AUTONOMOUS VEHICLE, AND ELECTRIC VEHICLE DEMAND

The following chapter details the findings of one of the papers I co-authored (Garrow, German, and Leonard, 2020). The original paper serves as a detailed review and meta-analysis of research from the transportation field related to AVs and EVs and research from the aerospace field related to aircraft. The analysis includes identifying key topics and findings within the existing research and further determining opportunities for future research. In particular, this chapter focuses on the demand modeling literature, as that topic is most relevant to the goal of this thesis.

2.1 Methodology

To identify relevant publications in UAM, we conducted a keyword search of "urban air mobility," "air taxi," and "UAM" in the AIAA publication database. A similar search was conducted on Scopus using the same keywords but adding exclusion terms for "drone" and "UAV." The searches were initially conducted in the spring of 2020 and were updated in mid-July 2020.

The search results included journal and conference publications relevant to UAM that were published from January 1, 2015, to June 30, 2020, in which the aforementioned keywords appeared in the title or abstract. A total of 251 publications were identified from the AIAA database and an additional 61 from the Scopus search.

To identify relevant EV and AV articles, we reviewed the table of contents of key journals from the transportation field from January 2015 to June 2020[2] and identified articles that were relevant based on their titles and abstracts. We explicitly decided not to use a keyword search for this part of the analysis, so that we could go through the titles and identify publications that were relevant to UAM research, such as ridesharing or carsharing, that may not directly fall into searches returned using EV and AV keywords. EV, AV, carsharing, and ridesharing are synergistic areas within the ground transportation field, given interest in using future AVs as an electric fleet that operates as a carsharing or ridesharing service. However, a simple search of "ridesharing" on Scopus of publications published since 2015 conducted in September 2020 returned over 2,500 publications. Thus, we opted to use a more directed approach by carefully reviewing titles and abstracts from selected journals to identify papers in the ground transportation literature that showed potential for having ideas, concepts, methods, or results that could inform UAM research.

Given our overarching objective in comparing the EV/AV and UAM fields is to glean insights from the EV/AV areas that may be applicable to the UAM area, we excluded some papers in the EV/AV areas that were not directly applicable to the UAM field. For example, papers that discuss strategies for safely merging AV ground vehicles into traffic are not applicable to UAM given UAM has another dimension for conflict avoidance and different traffic management rules than ground transportation modes. Similarly, when doing a detailed analysis of a particular area (such as demand segmentation), we tagged all

[2] In 2019, David Hensher, a transportation professor at the University of Sydney, identified and ranked the quality of transportation journals. We used this list to select the transportation journals that were ranked in the top two (of four) tiers that had published a non-trivial number of AV- and EV-related research over the past five years (Hensher, 2019).

articles that fit into the category, but then focused our in-depth discussion on the subset of articles most relevant to UAM (e.g., we exclude a discussion of how EV vehicle characteristics like acceleration influence EV purchases).

We reviewed articles from the following journals—the number of articles in total and those we included in our analysis are shown in parentheses: *Transportation Research Part A* (1,392 published; 125 inventoried); *Transportation Research Part B* (970 published; 62 inventoried); *Transportation Research Part C* (1,971 published; 100 inventoried); *Transportation Research Part D* (1,281 published; 124 inventoried), *Transportation* (545 published; 51 inventoried); and *Transportation Science* (444 published; 16 inventoried).

The final number of articles we identified includes 312 for UAM and 478 for EV/AV research. For each of the 790 articles, we identified research themes by associating up to six keywords based on a review of the abstracts (or where unclear, a review of the articles). For each publication, we recorded author and publication information. Information for each of these 790 articles, including DOI links, will be included in an Excel sheet as a supplemental document to the original paper (Garrow, German, and Leonard, 2020). Co-author Garrow, an expert in travel behavior modeling from civil engineering, tagged the articles related to EVs and AVs, and co-author German, an expert in aircraft design from aerospace engineering, tagged the articles related to UAM. While the subject classifications are arguably subjective, they nonetheless enable us to identify high-level trends across the fields.

2.2 Meta-Analysis of UAM Publications

Based on our review of UAM-related articles, we conducted a meta-analysis focused on two overarching themes: (1) categorization of the technical content of the articles, and (2) analysis of the affiliations of the authors. The former theme provides insights into the breadth and depth of the topics addressed in UAM research, and the latter provides insights into what nations, organizations, and individuals are actively focused on UAM research.

To categorize the content in the UAM-related articles, we first identified low-level topic categories that were present in multiple articles, and we created corresponding content tags. In defining these categories, we were guided in part by our knowledge of new technical topic areas related to eVTOL aircraft that are being actively addressed within the UAM community, e.g. "Distributed Electric Propulsion" and "Aero-Propulsive Interactions." We then grouped related low-level tags hierarchically under higher-level categories associated with traditional research disciplines related to aircraft technology and operations, e.g. "Propulsion," "Aerodynamics," and "Simulation." Finally, we grouped these higher-level categories into two overarching categories: "Aircraft Technology" and "Market and Operations." The resulting categorization reflects our attempt to identify and group common themes in UAM research cogently; however, we do not claim that the categorization is mutually exclusive, collectively exhaustive, or unequivocal.

The hierarchical categories are shown in Figure 1. The numbers in parentheses indicate the number of articles with lower-level tags assigned to the corresponding category. The number of articles indicated for each higher-level parent category are summative of all children tags for the category. Note that any one article is likely to have been assigned more than one tag based on the breadth of topics covered in the article. The individual low-level content tags corresponding to the overall categories are not shown in Figure 1 to limit the size of the figure; however, these tags will be provided in the spreadsheet provided as supplemental material to the original article (Garrow, German, and Leonard, 2020).

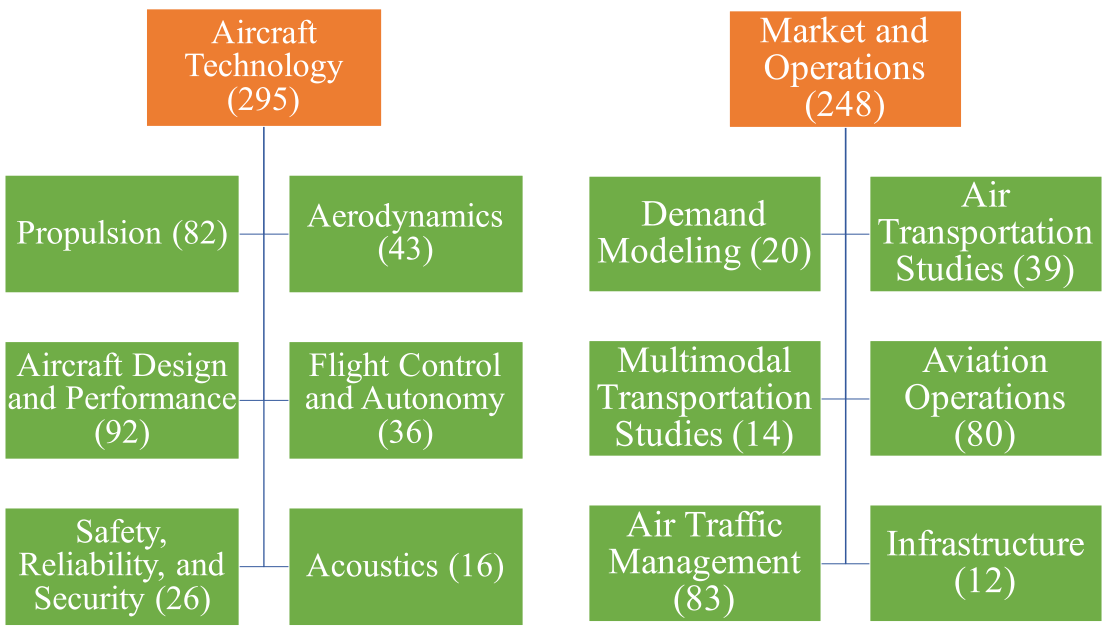

Figure 1 – UAM Themes from AIAA and Scopus Search, January 2015 to June 2020.

One main observation from this analysis is that current articles on UAM have a nearly even split of content related to “Aircraft Technology” (295 papers) and “Market and Operations” (248 papers). This thematic balance likely reflects an understanding within the community of the “chicken-and-egg” issue associated with the emergence of UAM, i.e., aircraft must be technically capable of serving the missions required for profitable large-scale UAM operations, and a market must exist for the types of missions and operations that can be supported given the technological limitations of emerging aircraft. A concrete example of this interplay is related to eVTOL aircraft with battery electric propulsion. These aircraft have the capability of being much quieter and more economical than current generation helicopters, potentially allowing widespread operations in urban environments at low ticket prices. However, battery electric eVTOL aircraft have very limited range and speed capability because of the low specific energy of current and near-term batteries, potentially limiting the potential for the aircraft to serve an adequate network of origins and destinations and to offer adequate travel time savings compared to other modes when trip times are dominated by ingress and egress on short-ranged flights.

In our meta-analysis of author affiliations, the 251 UAM-related articles from AIAA consisted of a total of 862 listed authors, many of whom were listed on multiple papers, resulting in 554 unique authors. Among the 554 unique authors, 44 percent are affiliated with an academic institution, and 31 percent are associated with NASA. The remaining 25 percent of authors are associated with U.S.-based and international companies and research agencies. The majority of authors in the AIAA database (83 percent) are affiliated with institutions in the U.S., and the country with the second-highest representation (7 percent) is Germany. As these statistics reveal, the majority of UAM research has been conducted by the U.S., and NASA has played a critical role in this research.

A similar meta-analysis was conducted with UAM articles returned from the Scopus search with AIAA publications excluded. The 61 UAM-related articles from the Scopus search consisted of a total of 175 listed authors and 141 unique authors. Of all 141 unique authors, 66 percent are affiliated with an academic institution, and 16 percent are affiliated with NASA. The remaining 18 percent of authors are affiliated with U.S.-based and international companies and research agencies. Similar to the results seen in the AIAA database, the majority of authors (52 percent) are affiliated with institutions in the U.S., and the country with the second-most representation in the Scopus search is Germany (20 percent). The country with the third-most representation is the Republic of Korea (4 percent). These statistics confirm the trends seen in the AIAA search—UAM research has been concentrated primarily among U.S.- and German-based researchers, and NASA has played a critical role.

2.3 Meta-Analysis of Ground Transportation Publications

To categorize the content of ground-transportation articles, we first identified broad topics. Many of these topics are overlapping and represent envisioned synergies across new technologies. For example, papers that discuss a future in which a shared fleet of AVs operate on batteries would be classified under the high-level categories of "Electric Vehicles," "Autonomous Vehicles," and "Carsharing." Once we identified broad topics, we tagged themes within each topic area that were potentially relevant for UAM research. The content tags are shown in Figure 2. The next section presents our review of demand tag in depth. One key observation can be made based on the overall tag findings: within the top-tier transportation journals identified on Hensher's list (2019), there were only four articles published on UAM. This highlights the opportunity for the transportation planning community to take a more active role in research related to the design and operations of UAM systems and apply insights they have gained through related research in the EV and AV fields to UAM.

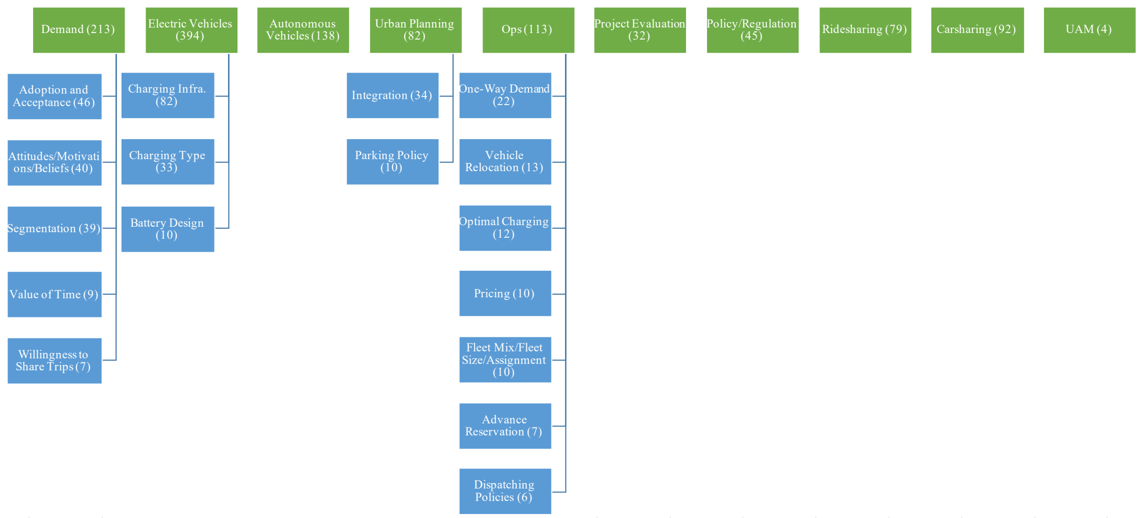

Figure 2 – Themes from Transportation Journals' Table of Contents Search, January 2015 to June 2020.

The 478 ground transportation articles from the journals *Transportation Research Part A (TR-A), TR-B, TR-C, TR-D, Transportation Science*, and *Transportation* consisted of a total of 1,594 listed authors, many of whom were listed on multiple papers, resulting in 1,154 unique authors. Among the 1,154 unique authors, 84 percent are affiliated with an academic institution. The remaining 16 percent of authors are associated with U.S.-based and international companies and research agencies. Among authors associated with academic institutions, 26 percent are affiliated with institutions in the U.S. The country with the second-highest representation (13 percent) in the ground transportation journal database is China, closely followed by Germany (9 percent). As these statistics reveal, the majority of ground transportation research has been conducted by the U.S., but the authors are much more diverse in their affiliated countries than the UAM authors. Ground transportation authors are also much more commonly affiliated with academic institutions compared to UAM authors.

2.4 Demand Modeling Literature

To date, the UAM and ground transportation communities have taken different approaches with respect to modeling demand. The UAM community is currently focused on conducting high-level assessments to understand if there are viable markets for UAM and how mission requirements for these markets (which tie directly to aircraft design specifications) vary across different cities. Identifying where UAM could offer door-to-door travel time savings compared to other modes is a key part of these high-level assessments. To this end, macro-level data of economic activity, aggregate data of commuter flows, and census and other government data are often used to estimate UAM market demand.

In contrast, the ground transportation community often conducts surveys to predict how individuals will respond to different operational, pricing, and policy measures. These surveys enable researchers to understand how opinions and intentions to adopt a new technology vary as a function of socioeconomic and sociodemographic (SED) characteristics, as well as attitudes and perceptions (e.g., is the individual tech-savvy?). Insights from these surveys can be helpful for identifying potential early adopters and designing marketing campaigns. Surveys also allow researchers to focus on specific questions, such as the willingness to travel with strangers in ridesharing situations or the value of times across different modes as a function of trip purpose. These and other questions will be relevant to the UAM community as they start conducting detailed assessments of which particular consumers will use UAM and how much they are willing to pay.

2.5 Conclusions Related to Demand Modeling

Based on the detailed review of literature in the original paper, several conclusions can be drawn (Garrow, German, and Leonard, 2020). Demand modeling within the UAM and EV/AV domains have focused on different objectives. Within the UAM field, the primary focus has been on determining if UAM is a viable concept—e.g., will enough people be willing to fly in these new air taxis and can the service be supported across different cities? Within the ground transportation field, EVs, AVs with lower levels of automation, and sharing services have already been implemented, allowing researchers to focus on understanding SED characteristics of early adopters or how individuals respond to different policy incentives and operational policies.

To the extent that individuals who are interested in EV, AV, and sharing modes will also be interested in air taxis, we would expect that early adopters of air taxis will be more likely to be male, have higher incomes, have pro-environmental attitudes and/or be tech-savvy, technology-oriented lifestyles and be the first to try out new products. These expectations have been confirmed in surveys of U.S. commuters by Boddupalli, Garrow, and German (2020) and Garrow, Roy, and Newman (2020).

The EV and AV literature have several findings that are relevant for the UAM community. To date, there has been a significant amount of research in the EV and AV literature that has looked at the timing of when adoption occurs, but only one paper in the UAM area, by Al Haddad et al. (2020). These technology adoption models can provide valuable information on the role of trust, safety, and perceived usefulness on the adoption of UAM. The literature across both the air and ground transportation areas show mixed reactions in the population with respect to autonomy. Finding ways to increase individuals' trust in autonomy would be a valuable direction for future research. For example, we may find that it is important to provide demonstrations of what it would be like to fly in a UAM using virtual reality and/or to provide safety information to increase individuals' comfort levels with the new technology. The role of social effects (like trusting perceptions of friends and family) has been shown to play a role in adoption of ground vehicle technologies and could be investigated in the context of UAM.

Unlike with ground transportation modes, individuals are more likely to expect to travel with strangers in an aircraft. It is, thus, unclear whether the same effects seen for ridesharing services will apply to UAM. One study, by Garrow, Roy, and Newman (2020) did find that younger commuters were less likely to take a UAM with strangers compared to older commuters. However, there is a research need to understand if the willingness to travel with strangers in a UAM aircraft varies across nations and trip purposes.

Perhaps one of the most interesting findings from the AV literature is that the VOT for commuters will decrease when ground AVs enter the market due to the ability for commuters to use their time more productively. From the UAM perspective, this is important as it suggests that AVs will compete more heavily with air taxis than with conventional autos and that additional travel time savings will be required for the air taxi mode relative to the AV. Potential productivity gains in an AV compared to an air taxi have not been explored in the literature, and there is a need to determine what levels of productivity would be achievable in a UAM vehicle and how productivity varies as a function of ride quality, trip duration, and other factors. Given the VOT decreases seen for

AV ground research, better understanding of VOT decreases for UAM vehicles—particularly as they relate to commute trips—is an important area of future research.

Another interesting avenue for future research would be to explore how AVs and air taxis will compete across different trip purposes as an air taxi system evolves and adoption rates increase across both new modes.

CHAPTER 3. A SURVEY TO MODEL DEMAND FOR EVTOL TRIPS TO AIRPORTS

The following chapter contains the main body of the AIAA paper that will be submitted in 2021. Appendix references and the formatting of the paper have been updated to correspond with the structure of the thesis rather than the structure of the AIAA paper. Sections including the abstract, conclusion, and acknowledgements have been omitted from this chapter, but will be included in the AIAA submission. Authors listed on the AIAA paper will be myself, Caroline E. Leonard[3], Laurie A. Garrow[4], and Jeffrey P. Newman[5].

3.1 Introduction

Many companies are developing prototypes for electric vertical take-off-and-landing (eVTOL) aircraft to serve as air taxis in cities. As of November of 2020, the Vertical Flight Society, which tracks progress in eVTOL aircraft, had catalogued over 350 eVTOL aircraft in development by different organizations worldwide (eVTOL news™, 2020). Companies are making investments based on the hypothesis that there will be strong consumer demand and to date several surveys have been conducted examining the potential for eVTOL air taxi service (e.g., see Boddupalli, Garrow and German, 2020; Garrow, Roy and Newman, 2020; Fu, Rothfeld, and Antoniou, 2019; Song, Hess and Decker, 2019). The majority of prior work has focused on examining eVTOL demand potential for commuter trips. However, several authors have noted that an air taxi shuttle to commercial airports may

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have higher demand potential, particularly as a first use case (Johnson, Riedel, and Sahdev, 2020; Mayor and Anderson, 2019; Booz Allen Hamilton, 2018; Thompson, 2018). Intuitively, this is because by taking an air taxi, individuals can avoid the cost of parking at the airport or taking a ride-hailing service to the airport. In addition, business air travelers whose trips are being reimbursed by their companies, a client, or other organization will have a higher willingness to pay for travel time savings that may be possible on an air taxi shuttle. This paper presents the details of a survey we designed to estimate air travelers' willingness to pay for an eVTOL air taxi shuttle to a commercial airport. The results of the survey will provide some of the first insights into the potential demand for eVTOL air taxi trips to commercial airports.

3.2 Sampling Plan

We are using a commercial opinion panel to survey air travelers in seven metropolitan areas in the U.S. Specifically, we are including individuals who have a home zip code within the Census-defined Combined Statistical Areas (CSAs) for Atlanta, Boston, Chicago, Dallas-Ft. Worth, Los Angeles, New York City, and the San Francisco Bay Area, and shown in Figure 3. Online databases were used to find the road (United States Census Bureau, 2019c), airport (Federal Aviation Administration, 2020), city (ArcGIS Hub, 2020), state (Esri, 2020), and CSA (United States Census Bureau, 2019b) shapefiles we used to generate Figures 3-10. We will survey 2,800 individuals (approximately 400 from each of the CSAs) with household before-tax annual incomes of at least $75,000. Our motivations for selecting these seven CSAs are described in the following pages.

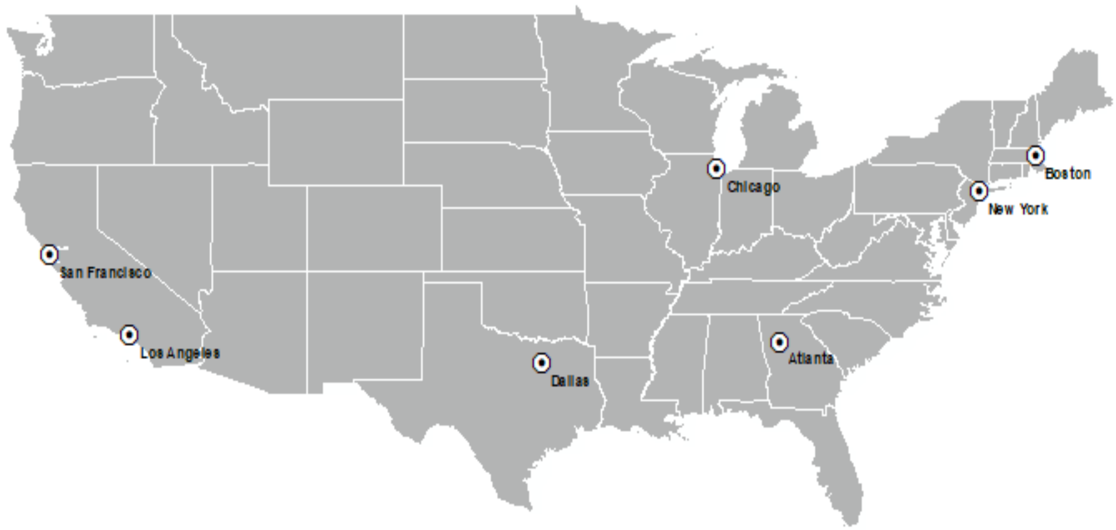

Figure 3 – Survey Cities.

3.2.1 Atlanta

Atlanta is a land-locked city in the Southeast that has no geographic features that help prevent outward growth expansion in the region. The sprawling region provides a spoke interstate system to different areas of the region and has many large employment centers along the Interstate 285 perimeter that surrounds Atlanta. The automobile-dominant mode share of the region, combined with the lack of natural boundaries that limit outward expansion and the spoke interstate feature, set the region apart from the other survey cities. Additionally, Atlanta's airport, Hartsfield-Jackson Atlanta International Airport (ATL), is ranked the number one commercial service airport by number of yearly enplanements according to the Federal Aviation Administration (FAA) (2018). The airport serves a massive population of not only Atlanta residents, but residents of surrounding

Georgia cities. ATL is 9.2 miles[+] from the city center, and with Atlanta's car-dependence and infamous traffic problem, residents may be willing to use air taxis to bypass this traffic for their airport trips.

Figure 4 – Atlanta CSA.

3.2.2 Boston

Boston is a city on the East Coast that is part of the Northeast Corridor. The Boston CSA has geographic features and transportation alternatives that influence airport trip mode choice. The Boston CSA borders the Atlantic Ocean and includes parts of Connecticut, New Hampshire, Massachusetts, and Rhode Island. The City of Providence, Rhode Island lies within the Boston CSA. The Boston Harbor, Cape Cod Bay, and Charles River are all geographic features that affect traffic patterns. The transit mode share is higher in the Boston region than in any other CSAs in our survey. Boston's main airport, Boston Logan International Airport (BOS), is located only 3.8 miles[+] from the city center, making

[+] These distances were found using Google Maps by mapping the shortest driving distance from the city to the airport.

it the most central airport in this study. However, the airport is separated by water from most of the rest of the city, meaning there are limited route options by ground transportation. Boston Logan has some competition with other airports in the Boston CSA, including Worcester Regional Airport (ORH), Manchester-Boston Regional Airport (MHT), and T.F. Green Airport (PVD), each of which are much further from the Boston city center, but serve demand of people living in the surrounding area.

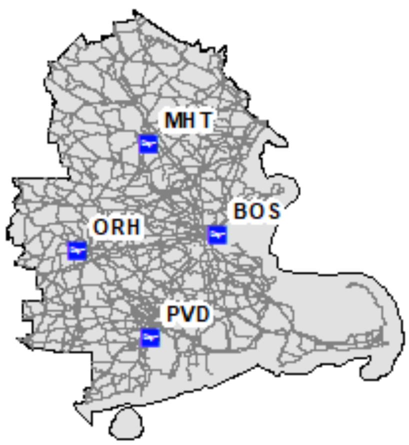

Figure 5 – Boston CSA.

3.2.3 Dallas-Fort Worth

Dallas-Ft. Worth is similar to Atlanta in that it lacks geographic features that limit sprawl and influence development patterns. Distinct from Atlanta, the interstate network was constructed in a grid-pattern between Dallas and Ft. Worth with many large business-attracting areas between the cities near the City of Arlington and along the perimeter of the cities. Dallas is one of two cities in the U.S. that Uber selected for testing eVTOL flights (Repko, 2018). The Dallas-Ft. Worth area's busiest airport is Dallas/Fort Worth International Airport (DFW), which is ranked as the fourth busiest airport based on number of yearly enplanements according to the FAA (2018). DFW is 20 miles[+] from the city center of Dallas, and 23 miles[+] from the city center of Fort Worth, making it one of the least central airports in this study. The other major airport in the CSA is Dallas Love Field Airport (DAL). DFW and DAL are close in proximity to one another (16.7 miles[+]), so they likely compete for much of the same traveler demand.

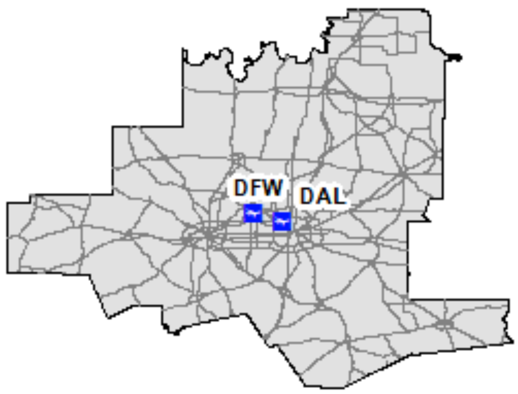

Figure 6 – Dallas-Ft. Worth CSA.

3.2.4 Los Angeles

Los Angeles is the second city in the U.S. that Uber selected for testing eVTOL flights and is one of two West Coast CSAs included in our study (Repko, 2018). The region is infamous for long commute times and for having one of the most congested interstate systems in the nation (Romero, 2016). Los Angeles has geographic features that act as barriers to development in particular areas of the region, e.g., the CSA borders the Pacific Ocean and has terrain features (such as mountains) that impact where development occurs and where the transportation network can be located. Los Angeles is unique among the

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[+] These distances were found using Google Maps by mapping the shortest driving distance from the city to the airport.

other cities in that from the 1970s until 2014, it had regulations requiring buildings above a certain height to have a heliport on their roof to assist in evacuations (Smith, 2014). This sets Los Angeles apart from other cities in that it already has an existing infrastructure in a downtown area that could potentially be converted to vertiports. Los Angeles' main airport is Los Angeles International Airport (LAX), which is ranked as the second busiest airport based on number of yearly enplanements according to the FAA (2018). This airport is 16.6 miles[+] from the city center, and similar to Atlanta, it is likely that the limited transit options and car-dependence in Los Angeles combined with the saturated roadways will push air travelers to choose an air taxi service that bypasses ground traffic as an alternative option for airport trips. Los Angeles also has many airports that potentially compete with LAX including Ontario International Airport (ONT), John Wayne Airport (SNA), San Bernardino International Airport (SBD), Hollywood Burbank Airport (BUR), and Long Beach Airport (LGB). These airports are spread out within the CSA, ranging from 22.3 miles[+] to 77.6 miles[+] from LAX and likely serve air travelers living in the areas surrounding the city of Los Angeles.

[+] These distances were found using Google Maps by mapping the shortest driving distance from the city to the airport.

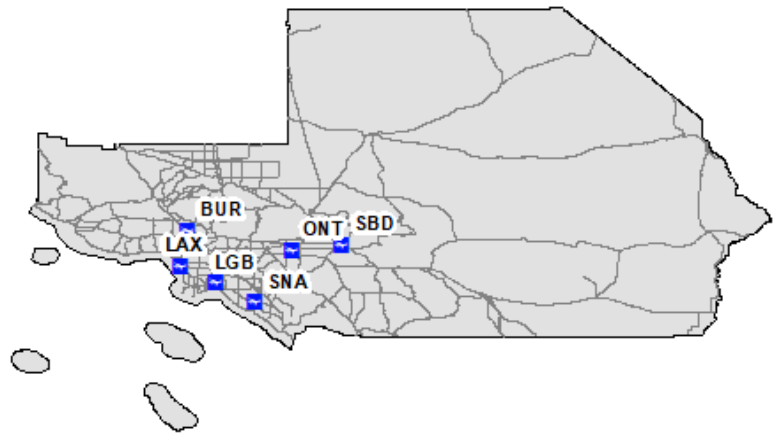


Figure 7 – Los Angeles CSA.

3.2.5 San Francisco

The San Francisco CSA was chosen because of its unique geographic features and reputation as an incubator of new technologies (Rampton, 2014). The Bay Area has three major cities (Oakland, San Francisco, and San Jose) within the San Francisco CSA. The San Francisco Bay only has four existing bridge crossings from the East Bay to areas in San Francisco and the cities of Silicon Valley. This physical barrier makes for challenging traffic patterns and could be an ideal pattern for future eVTOL air-taxi service. There are also key geographic features in the terrain that impact the location of existing transportation connections along the interstates, highways, and transit. San Francisco's major airport, San Francisco International Airport (SFO), is ranked as the seventh busiest airport based on number of yearly enplanements according to the FAA (2018). Other major airports in the area include Oakland International Airport (OAK), San Jose International Airport (SJC), and Charles M. Schulz-Sonoma County Airport (STS). These airports, particularly OAK and SJC, are likely to compete with SFO for travelers living closer to San Jose or Oakland.

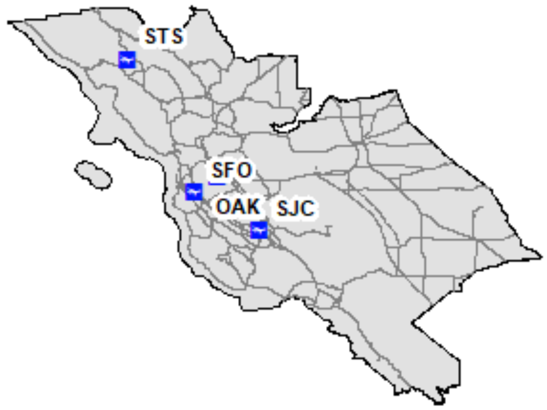


Figure 8 – San Francisco CSA.

3.2.6 New York City-Newark

Next, the New York City-Newark CSA was chosen because of existing successful helicopter services, Blade and Uber Copter, operating in this region. Blade offers an airport shuttle service between New York City and three area airports (JFK, LaGuardia, and Newark) (BLADE, 2020). Uber Copter offers a narrower service, with an airport shuttle traveling only from downtown Manhattan to JFK airport (Uber, 2020). While the city has a relatively robust transit network, there is existing demand for these air travel services for airport trips, which indicates that a similar on-demand eVTOL service may also be successful. The New York City-Newark CSA was also chosen because of its massive size; with a population of over 22.5 million residents, this CSA ranks as the largest by population in the United States according to 2019 estimates by the US Census Bureau (2019a). The busiest airport in this CSA, by FAA's latest ranking, is John F Kennedy International Airport (JFK), which has the sixth most yearly enplanements of all commercial airports in the US (Federal Aviation Administration, 2018). This is also the furthest airport from the

NYC city center (17.8 miles+ away). The other two major airports in this region, Newark Liberty (EWR) and LaGuardia (LGA), both rank in the top 21 busiest airports, and they are both more than 10 miles+ from the NYC city center as well (Federal Aviation Administration, 2018). Both the frequency of flights taking place at these regional airports and the relatively far distances from the city center to these airports indicate that the NYC-Newark CSA may be one of the CSAs with high demand for an air taxi service.

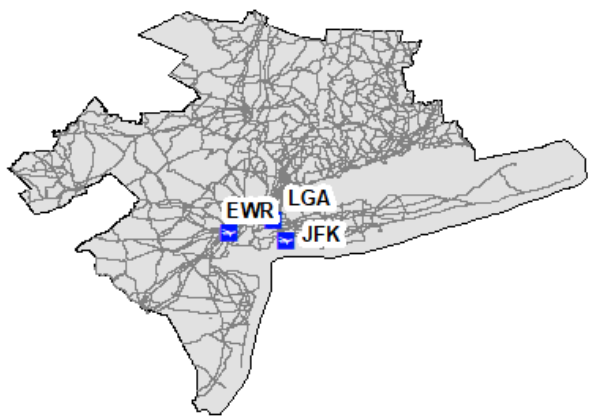


Figure 9 – New York City-Newark CSA.

3.2.7 Chicago-Naperville

Finally, the Chicago-Naperville CSA was chosen primarily because of the large population, the presence of two major international airports, and the existing traffic problems. The Chicago-Naperville CSA is the only Midwest CSA chosen, and it borders Lake Michigan, which acts as a barrier for development to the east. Chicago is home to Chicago O'Hare International Airport (ORD) and Chicago Midway International Airport (MDW), both of which rank within the top 30 busiest airports based on number of yearly

+ These distances were found using Google Maps by mapping the shortest driving distance from the city to the airport.

enplanements according to the FAA (2018), and both of which are more than 10 miles[+] from the Chicago city center. Chicago has some of the worst traffic congestion in the US, with major congestion on both the I-290 and I-90/I-94 corridors (INRIX, 2019). The Chicago-Naperville CSA is the third largest CSA by population in the United States according to 2019 estimates by the US Census Bureau (2019a).

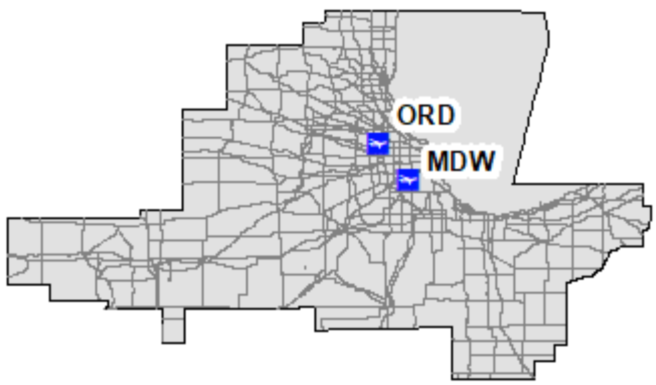


Figure 10 – Chicago CSA.

3.3 Survey Instrument

The survey instrument contains 11 parts. It includes approximately 90 questions in all, but some questions are not shown to all respondents, e.g., respondents are only asked if they paid for parking at the airport if they indicate that they arrived at the airport via a private vehicle. Appendix A provides complete details of the survey instrument and associated programming logic described in this section.

[+] These distances were found using Google Maps by mapping the shortest driving distance from the city to the airport.

3.3.1 Institutional Review Board Consent and Screening Questions

The first section contains the required Institutional Review Board (IRB) statement, provides compensation information, and asks respondents whether they agree to participate in the study. We state that as a participant, "You will complete a survey that asks you about your attitudes, travel patterns, and air travel experiences." We do not explicitly refer to an air taxi service in the introduction, to minimize biasing recruitment (people may be less inclined to respond if they have no interest in the service) and results (those who do respond may be more likely to answer favorably toward questions involving air travel service if they know that is our primary interest in conducting the survey).

The first section also contains screening questions used to ensure only responses are gathered from the target population. Only those individuals 18 years or older who took at least two roundtrips by air in 2019 (before COVID), have not moved residences since January 1, 2019, and have an annual household income of at least $75K are eligible to participate in the study. In addition, the individual must have taken either one business trip that was reimbursed by their company, a client, or other organization or one leisure trip that the individual paid for in cash (versus miles) in 2019 (before COVID). Individuals that work in the aviation industry or are full-time students are also excluded. Only those individuals who typically drive themselves to the airport, take a cab, or use a ride-hailing service such as Lyft or Uber qualify for the study. We use the home zip code to ensure that the respondent lives within one of the seven CSAs included in the study.

Some questions included in this section are used to stratify the sample and ensure minimum and/or maximum quotas are satisfied. Quotas associated with reimbursed business trips, household income, and air travel frequency in 2019 are shown in Table 1, Table 2, and Table 3. The quotas help ensure that the sample over-represents higher-income households, individuals who are frequent air travelers, and individuals who travel for business. We hypothesize that all of these characteristics will be associated with higher air taxi adoption rates.

Table 1 – Quotas Based on Trip Purpose and Geography. Total number of respondents = 2,800.

	Atlanta	Boston	Chicago	Dallas-Ft. Worth	Los Angeles	New York	San Francisco
Total number of respondents	400	400	400	400	400	400	400
Reimbursed business trip in 2019 (min quota)	200	200	200	200	200	200	200

Table 2 – Quotas Based on Annual Household Income. Total number of respondents = 2,800

Annual HH income	Quota
75-99K	700
100-149K	700
150-199K	700
200K+	700

Table 3 – Quotas Based on Air Travel Frequency in 2019 (Before COVID). Total number of respondents = 2,800.

# Trips by air in 2019	2-6	7-12	13-24	25+
Min count		560	560	280
Max count	560			

Based on our prior experience in conducting other studies of air travelers using a commercial online panel, we also impose quotas based on working status to ensure that leisure trips are not dominated by retirees or those who are not working. At least 75% of respondents (2,100) must be currently working full-time for pay, and a maximum of 10% of respondents (280) may be retired, be a homemaker, or not be currently working. The question asking about the respondent's employment status includes more options than typical. Due to the nature of the COVID-19 pandemic, there are more common possibilities for employment statuses. COVID-specific employment statuses were added to the traditional set of statements. For instance, if a person became furloughed or laid off during the pandemic, they can indicate that specifically instead of choosing "I currently do not work." This is an important distinction to capture because it indicates that the respondent's employment status is not typical, and therefore the past travel experiences they draw from to answer later questions may differ in the future as a result of their current employment status. Employment statuses related to the COVID-19 pandemic may also be temporary setbacks; as the economic impact of the pandemic decreases, individuals may return to their original employment statuses. See Question 11 in Appendix A for more details.

3.3.2 Opinions about Travel

The second section of the survey asks participants about their views on a variety of issues directly or indirectly related to travel. We will use the questions in this section (as well as those collected later in the survey) to conduct factor and cluster analyses, which will provide insights into the types of consumers for which air taxi service is most attractive. See Garrow et al. (2020a) and Garrow et al. (2020b) for examples of factor and cluster analysis that have been used for market segmentation analysis in the context of UAM.

To conduct a factor analysis, we need to identify constructs that we hypothesize will influence demand for air taxi services. We include six constructs in this section, shown in Table 4. Twelve questions are asked, to obtain measurements associated with these constructs. For each question, respondents report how much they agree or disagree with the statement using a Likert-type scale with five categories: strongly disagree, disagree, neutral, agree, and strongly agree.

Table 4 – Constructs and Survey Questions Related to Opinions about Travel.

Survey Question	Construct	Direction
[2]I am fine with not owning a car, as long as I can use or rent one any time I need to	Pro-collective modes	+
[3]Using a ride-sharing service, such as Lyft or Uber, is more convenient than driving	Pro-collective modes	+
[3]Whenever practical, I prefer to drive rather than take transit	Pro-collective modes	-
[3]I like meeting new people through ridesharing	Travel Sociability	+
[3]I'm uncomfortable traveling in the same car with strangers	Travel Sociability	-
[1]I don't mind sharing a ride with strangers if it reduces my costs	Travel Sociability	+
[2]I would tend to feel sick if I tried to read while in a moving vehicle	Motion sickness	+
[4]I rarely consider the impact on the environment in my travel choices	Pro-environment	-
[5]I limit my driving to help improve air quality	Pro-environment	+
[1]Even if I can use my travel time productively, I still expect to reach my destination as fast as possible	Productivity	+
[5,6]I would usually rather have someone else who is trustworthy do the driving	Control	-
[6,7]Being in a car makes me nervous if someone else is driving	Control	+

Notes: [1]Lavieri and Bhat (2019) [2]Kim, Mokhtarian, and Circella (2019) [3]Garrow et al. (2019) [4]Al Haddad et al. (2020) [5]Mokhtarian, Salomon, and Redmond (2001) [6]Haboucha, Ishaq, and Shiftan (2017) [7]Circella (2020)

Finally, we include a “trap question” in this section, in which we asked participants to select “Agree” to confirm they are reading the questions. We terminate the survey for those who do not select the correct response, given it is more likely these individuals are not paying attention to the survey questions (and would potentially bias survey results if they complete the entire survey).

In factor analysis, it is common to ask at least two questions associated with each construct, and preferable to vary the directionality of the questions to be (collectively) both “positively” and “negatively” associated with a given construct. Stated another way, the wording of the two questions associated with the construct is designed so that an individual who selects “agree” or “strongly agree” on one question would tend to select “disagree” or “strongly disagree” on the other question. The questions are ordered differently in the survey than in Table 4, to minimize the consistency bias associated with having the items pertaining to the same construct adjacent to each other, to counteract respondents’ tendencies to fall into an automatic response pattern (e.g., a predictable alternation of positively and negatively oriented questions), and to reduce any unintended carryover effects from one question to the next.

3.3.3 Opinions about Air Travel

The third section asks participants about their opinions related to air travel. Similar to the previous section, the results from these questions will also be used to perform factor and cluster analysis. This section includes four constructs composed of eleven statements. These statements and their corresponding constructs are listed in Table 5. The same Likert scale choices used for the previous section are listed for each statement in this section in order to measure the respondent's level of agreement with the statement.

Table 5 – Constructs and Survey Questions Related to Opinions About Air Travel.

Survey Question	Construct	Direction
I prefer to drive and park at or near the airport	Airport Mode Preference	+/-
I prefer to take a ride-hailing service such as Lyft or Uber to the airport	Airport Mode Preference	+/-
I prefer to have family or friends drop me off at the airport	Airport Mode Preference	+/-
I prefer to take public transit to the airport	Airport Mode Preference	+/-
[1]I like traveling by airplane	Air Mode Preference	+
[1]Traveling by air makes me nervous	Air Mode Preference	-
I am willing to spend extra time getting to and from the airport in order to save money	Cost Sensitivity	+
I like getting to and from the airport as quickly as possible, even if it costs more	Cost Sensitivity	-
[2]Self-driving cars are appealing to me because they will allow me to use my travel time to the airport more productively	Pro-AV Attitude	+
Self-driving cars are appealing to me since I would not need to park at or near the airport	Pro-AV Attitude	+
Driving is safer overall than using a self-driving car	Pro-AV Attitude	-

Notes: [1]Garrow et al. (2019) [2]Lavieri and Bhat (2019)

3.3.4 Current Travel Behavior

The fourth section of the survey asks questions about the individual's current travel behavior including:

- Household car ownership
- Whether the individual has taken a ride-hailing service and if so, how the individual typically uses these services
- How the individual expects his or her travel to change a year from now
- How the individual expects his or her residential location to change a year from now

This section also asks questions about the individual's air travel experience including:

- Whether the individual has traveled in a small aircraft
- The individual’s preferred mode choice to travel to the airport and what influences this choice
- The individual’s comfort level with traveling by air during the COVID-19 pandemic
- The number of roundtrips the individual has taken by air since April 1, 2020

3.3.5 Most Recent Air Trip

The fifth section of the survey asks questions about the individual's most recent air trip. If the individual indicates in the screening questions that they had taken at least one business-related trip paid for by their company or an organization in 2019, they will be asked about their most recent business-related trip of this nature. If not, the individual will be asked about their most recent leisure trip that they paid for themselves in cash. Questions about the trip include:

- When the air travel trip took place
- Whether or not the trip was international
- How far in advance the ticket was purchased
- How much the air travel ticket costed
- The reason for taking the air travel trip
- How many total people the individual traveled with and among those how many were children
- How long the trip was
- How many bags the individual and their party checked and carried on the plane
- Whether or not the individual paid baggage fees
- The class of service used on the trip and whether or not a free upgrade was used

- Which airport the individual flew out of (only major airports in the individual's CSA were displayed as choices; these choices include the airports shown in Figures 4 to 10)
- The travel mode used by the individual to arrive at the airport
- Whether or not the individual paid to park at the airport, and if so, how much parking cost
- Where the individual started their trip to the airport and how far it was from the airport
- Whether or not the individual experienced traffic congestion during their trip to the airport
- Which airport the individual flew into at their destination
- How the individual got from the destination airport to his or her final destination

3.3.6 Introduction to Self-Driving Cars

The sixth part of the survey introduces the concept of self-driving cars and shows participants three images based on designs reported in the press. At the time of this publication, these images were available at Caricos.com (2019), Thepositive.com (2019), and Media.treehugger.com (2019). We edited these images for the survey, e.g., we removed a steering wheel to better reflect a fully autonomous vehicle. We use a bullet-pointed list to describe the self-driving cars and include information about the design, operation, and safety features. The description, which is based on Mokhtarian (2017), includes the following:

- Driverless cars would be at least as safe as today's cars are and they would be generally affordable.
- The car could be equipped with services such as an office, a television, or a small fridge for snacks.
- The car could be equipped with power outlets to keep your laptop and phone fully charged.
- You could send an empty self-driving car somewhere to pick up your children or groceries, or to park after dropping you off at work or other locations.
- You could let a self-driving car take you places while you are sleeping.

Based on this initial description, we ask individuals how appealing the design is to them and how likely they would be to use or own it. Consistent with Al Haddad et al. (2020), we also ask a question about when the individual would be likely to adopt self-driving cars (in its first year of operation, in its second or third year of operation, … never). We then present respondents with potential features of the self-driving car and ask them if they would be more or less likely to use it with these characteristics. The tested features include ownership status, the presence of other passengers, and activities that would be possible during the trip. Next, we ask whether or not the respondent would move to a different residential location and whether or not the respondent would change the number of vehicles his or her household owns if he or she could regularly take a self-driving car to and from work.

3.3.7 Introduction to Air Taxis

The seventh part of the survey introduces the concept of eVTOL aircraft for air taxi services and shows participants three images based on designs reported in the press. At the time of this publication, these images were available at Donovan (2019), Velocci (2019), and Aurora Flight Sciences (2020). We use a bullet-pointed list to describe the aircraft and include information about the design, operation, and safety features that are consistent with how we described these aircraft on prior surveys (Binder et al., 2018; Garrow et al., 2019):

- Are battery powered
- Carry two to four passengers
- Travel up to 50 miles within a city at cruise speeds of 150 mph
- Have efficient security checks with no lines
- In the near-term, would be flown by certified pilots on-board the aircraft
- Take off and land vertically like a helicopter
- Take off and land at locations in a city called vertiports such as tops of buildings and parking decks
- Operate out of vertiports that would be located 0-5 miles from your home and airport locations
- Have limits on how much baggage you can bring onboard, just like a commercial aircraft

- Are much quieter than helicopters, both for the community and for the occupants of the aircraft
- Travel at about the altitude where traffic helicopters fly
- Do not fly in hazardous weather conditions (such as thunderstorms)
- Meet stringent safety requirements mandated by the U.S. Federal Aviation Administration

Images of three aircraft including the Bell Nexus, Airbus Vahana, and the Aurora Flight Sciences Pegasus passenger air vehicle (PAV) are then shown to respondents.

Based on this initial description, we ask individuals how appealing the design was to them, how likely they would be to use it, and when they would be likely to use it. We then present respondents with potential features of the eVTOL aircraft and ask them if they would be more or less likely to use it with these characteristics. The tested features include fuel/battery combinations, a parachute for the aircraft, and multiple propellers for redundancy. We then ask how appealing it would be to use an air taxi for different trip purposes, including airport and non-airport trips, and how much more or less likely they would be to use an air taxi if it used certified autonomy, included a ride guarantee, or operated in different weather conditions. We include two questions related to how frustrated the individual would be with different delays and what refund policy would be appropriate for a given delay. We continue by asking six questions related to eVTOL perceptions (reaction to battery technologies, pros/cons of proximity, and overall impressions, shown in Table 6. Next, we ask whether or not the respondent would move to a different residential location and whether or not the respondent would change the number of vehicles his or her household owns if he or she could regularly take an air taxi to and from work.

Table 6 – Constructs and Survey Questions Related to Perceptions.

Survey Question	Construct	Direction
[1]I like that these aircraft can take off and land close to my home and work locations	Proximity	+
[1]I would be concerned to fly in an aircraft that takes off and lands vertically within a city with tall buildings	Proximity	-
[1]I like the idea of battery-powered aircraft for helping the environment	Battery technology	+
[1]I would be concerned to travel in a battery-operated aircraft	Battery technology	-
[1]I would find it exciting to travel in one of these eVTOL aircraft	Overall impression	+
[1]These aircraft would cause more problems than they would solve	Overall impression	-

Note: [1]Garrow et al. (2019)

3.3.8 Trade-Off Questions

The eighth part of the survey contains eight questions as shown in Figure 11 (these images, and others included in the survey, are reprinted here from the Creative Commons Attribution license (Icons8, 2020; Kaito, 2020; Oleynic, 2020)). Each question presents three hypothetical options for traveling to the airport and asks which one the respondent would choose. The introduction to the trade-off questions is presented to respondents as follows (using the business trip context as an example):

We would like for you to compare three hypothetical options for traveling to the airport. The first option is to drive yourself and park at the airport using a conventional auto. The second option is to use a ride-hailing company (Lyft/Uber) to travel to the airport. The third option is for you to take an air taxi.

In all cases, we show you the door-to-door travel time to go from your home to the check-in area at the airport.

For the auto option:

- The round-trip cost includes gas and parking in the daily lot at the airport.
- It is possible that when you arrive at the airport, the daily parking lot is full, in which case you would have to park in the economy lot. For example, a parking availability probability of 90% means that you would be able to park in the daily lot 9 out of 10 times you went to the airport.

For the ride-hail option:

- The trip may be in a conventional auto with a driver or it may be in an autonomous (driverless) auto.

For the air taxi option:

- The vertiport (or location) where the air taxi departs is within 5 miles of your home.
- You can drive your car to the vertiport and park for free or have someone drop you off.
- The vertiport where the air taxi lands is located at the airport.

- A ride guarantee may be provided, meaning that if the air taxi can't fly, you get preferential access to a Lyft or Uber ride at a price that is the same or lower than the air taxi.
- The air taxi can be flown by a pilot or it can be flown autonomously (without a pilot on board).
- Air taxi operators have different on-time performance records. For example, an on-time performance of 99% means that 99 out of every 100 air taxi trips arrive at the airport on-time.

For the questions that follow, assume you are traveling **after COVID on a four-day/three-night business trip that will be reimbursed by your company or a client.**

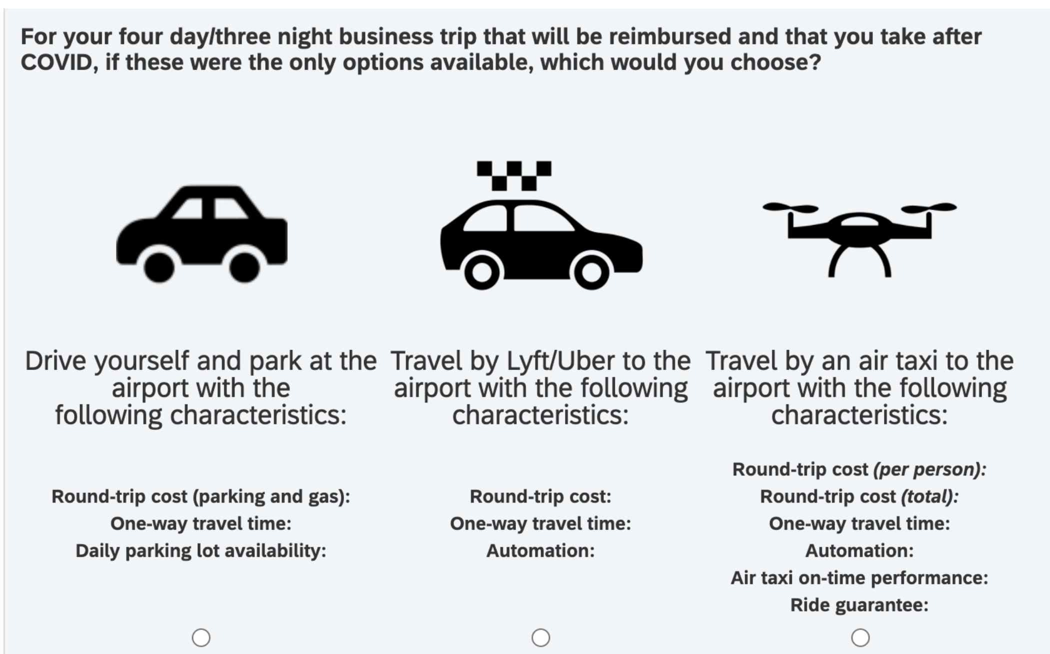


Figure 11 – Example Trade-Off Question.

We include several attributes in our trade-off questions such as travel time, cost, and the other attributes shown in Table 7, Table 8, Table 9. For travel times and travel costs, we set levels based on distance ranges to the airport. We determined distance ranges based on the distribution of distances from residences with household incomes greater than $75K to the nearest airport. To do this, the numbers of high-income households in each zip code were found using the CSA boundaries and household incomes at the zip code level (United States Census Bureau, 2019b; ArcGIS Hub, 2018). The centroids of each zip code were located, then distances were calculated between the centroids and each major airport in the CSA (Federal Aviation Administration, 2020). Plots illustrating these distances are included in Appendix B.

Four distance ranges were used to generate choice sets: less than ten miles, 11 to 20 miles, 21 to 40 miles, and 41 miles or more. For the auto mode, we selected four levels to represent door-to-check-in times that would reflect realistic ground travel times under free-flow and congested traffic conditions as well as time to travel from the parking lot of the airport to the check-in area. Given ride-hailing is subject to the same traffic conditions as auto and includes a wait time at the start of the trip yet eliminates the need to travel from the parking lot of the airport to the check-in area, we used two travel times as levels for ride-hailing that were the same as the two middle levels used for auto. For the air taxi, we based travel times on an average cruise speed of 150 mph and included 5 to 10 minutes of access and egress times.

For costs, we assumed that individuals would be traveling for a four-day/three-night trip (and in the trade-off questions we ask them to assume they are traveling for this period of time). For the auto mode, we used airport websites to obtain information on the cost of parking in the daily lot at the major airport(s) in the study areas. For Atlanta ATL and Dallas DFW airports, the daily cost of parking was about $20 per day whereas at the other airports, the daily cost of parking was about $40. For shorter trips, the cost of gas did not change the overall potential range of realistic prices too much, whereas for longer trip ranges, the cost of gas did have a larger influence.

For ride-hailing, we based our cost estimates on a formula provided for Uber that is \$0.80 base fare + \$0.21 per minute + \$1.10 and used a formula to estimate cost to the airport, also allowing for specific airport fees that may be added on (HyreCar, 2020). For air taxi, we loosely based prices on the short-term and near-term price-per miles reported in the literature but rounded prices to the nearest \$15 and ensured some air prices for some cities were less than a per-person bases for shorter distances to represent longer-term competitive cost structures.

Table 7 – Attributes and Levels included in Trade-Off Questions (Excluding Time and Cost).

Attribute	Definition	Levels
Daily parking lot availability	Probability (%) the daily parking lot is available when you arrive at the airport	50, 75, 90, 99
Automation	For ride-hailing, whether or not there is a driver For air taxi, whether or not there is a pilot on board	Driver present, no driver present or Pilot on board, pilot not on board
Air taxi on-time performance	Probability (%) the air taxi arrives to the airport on-time	80, 90, 95, 99
Ride guarantee	Whether or not a discounted ride on Uber/Lyft is provided if the air taxi cannot fly (e.g., due to bad weather)	Yes, No

Table 8 – Travel Time Levels Included in Trade-Off Questions.

Distance	Auto	Ride-hailing	Air Taxi
Less than 10 miles	20, 25, 30, 35	25, 30	10, 15, 20, 25
11 to 20 miles	25, 30, 35, 40	30, 35	15, 20, 25, 30
21 to 40 miles	35, 45, 55, 65	45, 55	20, 25, 30, 35
41 miles or more	45, 60, 75, 90	60, 75	25, 30, 35, 40

Table 9 – Per-Person, One-Way Cost Levels Included in Trade-Off Questions.

Distance	Auto – Atlanta and Dallas	Auto – Other Cities	Ride-hailing	Air Taxi
Less than 10 miles	40, 45	80, 90	15, 20	35, 75, 100, 125
11 to 20 miles	45, 50	80, 90	20, 25, 30	50, 75, 100, 150
21 to 40 miles	45, 50, 55	80, 90	30, 40, 50, 60	75, 100, 150, 200
41 miles or more	50, 60, 70	90, 100, 110	55, 65, 75, 85	75, 100, 150, 200

Given the number of attributes in our trade-off questions, combined with the number of levels that we want to test, we would have to ask each individual respondent 32 trade-off questions, which clearly is not realistic. In these cases, it is common to create blocks of questions so that each respondent sees no more than eight trade-off questions. Respondents are then randomly assigned to one block (which contains eight questions). We will be creating a total of 256 trade-off questions, representing a total of 4 distance ranges × 2 daily parking rates × 4 blocks × 8 questions per block.

The design of these trade-off question blocks is generated using Ngene (ChoiceMetrics, 2018). Ngene is a software distributed by ChoiceMetrics that can be used to generate an efficient design for a mixed logit model, among other stated choice experimental designs. Ngene is the preferred software for this type of survey because it allows you to generate a design using any number of discrete or continuous attribute levels. The primary inputs to Ngene are the utility functions for the three modes: car, ride hail, and eVTOL. These utility functions consist of coefficient estimates and levels for each attribute (cost, travel time, parking availability, automation, on-time performance, and ride guarantee). The coefficient estimates used in these utility functions are based on prior studies of air taxi mode choice for commuters and are listed in Table 10 (Boddupalli, Garrow, and German, 2020; Garrow, Roy, and Newman, 2020). The levels used in the utility functions are shown in Tables 7, 8, and 9.

Table 10 – Coefficient Estimates Used in Ngene Model.

Variable	Coefficient
Constant – Car	0.835
Constant – Ride Hail	0.597
Constant – eVTOL (reference)	0
Door-to-door travel time – Car	-0.03
Door-to-door travel time – Ride Hail	-0.03
Door-to-door travel time – eVTOL	-0.03
Cost – Car	-0.143
Cost – Ride Hail	-0.163
Cost – eVTOL	-0.097
Automation – Ride Hail	-0.1
Automation – eVTOL	-0.15
Guaranteed ride – eVTOL	0.158
% on time to airport – eVTOL	0.1
% parking availability at airport – Car	0.01

To illustrate how these functions are coded into Ngene, an example scenario has been run using the preliminary attribute levels for a scenario in which a single passenger will be flying out of ATL airport and lives within 10 miles of the airport. Figure 12 shows the code used in Ngene for this scenario. The four output question blocks for this example scenario are included in Appendix C. In the final submission of this paper to AIAA, an appendix will be added which will show the levels corresponding to the full set of 256 trade-off questions. These levels are pending approval from the project sponsor at the time of the submission of this thesis, so they have been excluded from the thesis.

```
Design
;alts = car, evtol, rh
;rows = 32
;block = 4, minsum, total(3 secs)
;eff = (mnl,d)

;model:

U(car) = beta.car[0.835] + beta_cost_car[-0.143]*cost_car[40,45]
+ beta_time[-0.03]*time_car_[20,25,30,35]
+ beta_parking_avail[0.01]*parking_avial[50,75,90,99]/

U(rh) = beta.rh[0.597] + beta_cost_rh[-0.163]*cost_rh[15,20]
+ beta_time[-0.03]*time_rh[25,30]
+ beta_automation_rh[-0.1]*automation_rh[0,1]/

U(evtol) = beta_cost_evtol[-0.097]*cost_evtol[35,75,100,125]
+ beta_time[-0.03]*time_evtol[10,15,20,25]
+ beta_automation_evtol[-0.15]*automation_evtol[0,1]
+ beta_on_time[0.1]*on_time[80,90,95,99]
+ beta_guarantee[0.158]*guarantee[0,1]


$
```

Figure 12 – Example of Ngene Code Used to Generate Trade-Off Questions.

As part of this trade-off questions section, we keep track of the number of times the respondent selects each mode. If the individual never selects air taxi, we ask a 9th trade-off question where air taxi clearly dominates the choices along all dimensions to help determine whether the individual is a "never adopter" or whether the individual is sensitive to time-cost trade-offs.

We ask a final trade-off question that only includes traditional auto and ride-hailing with a driver to represent current market conditions. This last trade-off question can be used to weight the survey data to represent current market shares for the drive-and-park and ride-hailing modes. See Glerum et al. (2016) for details on this adjustment procedure.

3.3.9 Lifestyle and Attitudes

The ninth section asks participants about their personal lifestyle and opinions not directly related to travel. Similar to sections *3.3.2* and *3.3.3*, the results from these questions will also be used to perform factor and cluster analysis. This section includes four constructs composed of nine statements. These statements and their corresponding constructs are listed in Table 11. The same Likert scale choices used for sections *3.3.2* and *3.3.3* are listed for each statement in this section in order to measure the respondent's level of agreement with the statement.

Table 11 – Constructs and Survey Questions Related to Lifestyle and Attitudes.

Survey Question	Construct	Direction
[1]I like to wait a while rather than being the first to buy a new product	Early Adopter	-
[1,2,3]I often introduce new trends to my friends or family	Early Adopter	+
I like that companies can tailor products to my preferences, even if it requires me to provide personal information	Privacy Concern	-
I'm concerned that technology invades my privacy too much	Privacy Concern	+
[3]For me, a lot of the fun of having something nice is showing it off	Status-Oriented	+
When making a purchase, I value functionality more than the status of its brand	Status-Oriented	-
I feel as if I need to make the most of every minute	Time Pressure	+
[4]Having to wait can be a useful pause in a busy day	Time Pressure	-
[4]Having to wait is an annoying waste of time	Time Pressure	+

Notes: [1]Kim, Mokhtarian, and Circella (2019) [2]Mokhtarian, Ory, and Cao (2009) [3]Neufeld and Mokhtarian (2012) [4]Garrow et al. (2019)

3.3.10 Use of Technology

Given prior studies that have found adoption of new transportation modes is associated with current use of technology, we ask how often individuals use smartphones, desktop computers, wearable technologies such as a smart watch of Fitbit and how often they post on Facebook, Twitter, Instagram, LinkedIn, and WhatsApp and similar applications (Kim, Circella, and Mokhtarian, 2019; Al Haddad, 2020).

3.3.11 Additional Socio-Economic Information

We conclude the survey by asking for socio-demographic and socio-economic information not already obtained for screening or quotas. These questions include whether the individual lives in an urban, suburban, small town, or rural area, gender, education level, number of adults and number of children under 18 living in the household before COVID, and ethnicity. A trap question to check for fatigue is also included in this section.

CHAPTER 4. CONCLUSIONS AND FUTURE RESEARCH

4.1 Conclusion

This thesis serves as my final and most significant contribution during my master's degree program. This work follows my prior contributions which include co-authorship on three prior papers. These papers were all directly connected to the work in this thesis in some way: Roy et al. (2020b) use socio-demographic traits of the census-tract level population in Atlanta to predict airport shuttle trips; Garrow et al. (2020b) conduct factor and cluster analysis based on results from a survey measuring demand for an air taxi service for commuters; and Garrow, German, and Leonard (2020) compile a database of over 800 sources related to UAM, AVs, and EVs, allowing them to extract trends in the literature and further recognize the gaps in research. My contribution to these papers led me to this thesis.

This paper described the sampling plan and survey instrument that will be used to forecast air taxi demand for airport trips. The survey will be distributed to 2,800 respondents in seven CSAs in the U.S.: Atlanta, Boston, Chicago, Dallas-Ft. Worth, Los Angeles, New York City, and San Francisco Bay Area. The survey includes questions related to respondents' opinions about travel and air travel, their current travel behavior, their most recent air trip, and their opinions about self-driving cars and air taxis. Respondents then answer a series of trade-off questions. For these questions, respondents are presented with scenarios in which they must choose between three travel mode options for a hypothetical airport trip based on characteristics like cost and travel time. The survey concludes with questions related to the respondent's lifestyle and attitudes, his or her use of technology, and his or her socio-economic characteristics.

Given the high cost of daily parking at many airports and the high cost of ride-hailing for longer distances, air taxi may be more competitive with traditional modes, particularly for reimbursed business trips. In that way, I expect the results from this survey to be similar but different than the results gathered from prior surveys of commuters (Booz Allen Hamilton, 2018; Thompson, 2018; Fu, Rothfeld, and Antoniou, 2019; Song, Hess and Decker, 2019; Binder et al., 2018; Garrow et al., 2019). I hypothesize that compared to conventional auto, ride-hailing will be more competitive for shorter-distance trips, air taxi will be more competitive for longer-distance trips, and that very few self-paid leisure trips with three or more travelers will consider an air taxi. I also hypothesize that the timing of adoption of air taxis and AVs will be related to the "straight-lining" phenomena observed in prior commuter surveys where a non-trivial percentage of respondents never chose air taxi as an option across eight trade-off questions.

4.2 Limitations

Like with any survey, there are limitations to the survey presented in this paper that should be considered. First, the survey will be distributed in January 2021, during which the COVID-19 pandemic is still impacting people's lives in significant ways. While the survey attempts to capture people's travel patterns before the pandemic, there is no guarantee that travel will return to "normal" even years into the future. Another limitation is the number of cities surveyed. It is the hope that by choosing the seven study CSAs, we are capturing cities that are most likely to generate air taxi airport shuttle demand, but surveying air travelers in other cities may reveal other useful trends.

There are also limitations associated with administering a fully-online, commercial opinion panel survey. While online surveys are easier to distribute and analyze than mail-back or telephone surveys, internet accessibility issues are often cited as a main limitation to online surveys (Adler et al., 2002; Wright, 2005; Kim, Mokhtarian, and Circella, 2019). This limitation is unlikely to significantly bias the results of this survey because the target population consists of high-income (>$75K household income) and primarily (75%) full-time working adults, whereas internet and computer accessibility limitations affect mainly the lower-income and/or elderly population. The main limitation to an online commercial opinion panel for this study is the fact that individuals who voluntarily enroll to participate in the survey will likely share similar characteristics. They may be younger, highly educated, or tech-savvy, for example (Kim, Mokhtarian, and Circella, 2019). This may limit the generalizability of the results to the greater population of interest.

4.3 Next Steps

The data collected in this survey will lend itself toward future work. This work will likely focus on mode choice modeling and modeling the timing adoption for air taxis and autonomous ground vehicles. Additionally, the data collected will be examined using factor and cluster analysis, similar to that of Garrow et al. (2020b), to better understand the market segmentation for an airport shuttle service.

Beyond this survey and the analysis of the data collected from this survey, this work contributes to an up-and-coming field of research with many unanswered questions. Once demand for air taxi airport shuttles can be better predicted using data from this survey and similar surveys, there are many steps to the implementation of such a service that would be worth studying. For example, researchers may look into optimal vertiport placement strategies, air traffic control coordination, or the potential impact on the electric grid, among other topics.

4.4 Supplemental Materials

Appendix A contains the survey instrument. Appendix B contains the distribution of distances from residences with annual incomes above $75K to the nearest airport. Appendix C contains the output table of trade-off question blocks for the example scenario detailed in Section *3.3.8.* The appendix containing the levels used for the full set of 256 trade-off questions is pending approval from the project sponsor and has been omitted from the thesis.

APPENDIX A. AIR TAXI SURVEY INSTRUMENT

SECTION 1: IRB, Screening and Qualification Criteria

Programming notes: IRB consent form is shown, and participant agrees to consent to participating in the survey.

1. What is your five-digit home zip code?

Programming notes: Zip codes are validated and must be a zip code in the CSAs of Atlanta, Boston, Chicago, Dallas-Ft. Worth, New York, Los Angeles, or San Francisco.

2. What was your five-digit home zip code on ***January 1, 2019***?

Programming note: If zip code is different than zip code from Q1, new zip code must be within the same CSA as the first zip code from Q1.

3. What is your age in years?

   ◯ 17 and younger

   ◯ 18 - 24 years

   ◯ 25 - 34 years

   ◯ 35 - 44 years

   ◯ 45 - 54 years

   ◯ 55 - 64 years

   ◯ 65 and older

Programming note: Must be 18 or older to participate.

4. What was your total household income before taxes and deductions during the past 12 months?

   ◯ $0 - $74,999

   ◯ $75,000 - $99,999

   ◯ $100,000 - $149,999

   ◯ $150,000 - $199,999

   ◯ $200,000 or more

Programming note: Must have an annual household income of 75K or more to participate.

5. How many roundtrips by air did you take in 2019 ***(before COVID)***?

 ◯ None

 ◯ 1

 ◯ 2

 ◯ 3 to 6

 ◯ 7 to 12

 ◯ 13 to 24

 ◯ 25 or more

Programming note: Must have taken 2 or more trips in 2019 to participate.

6. Did you take any **business-related** air trips in 2019 ***(before COVID)*** that your company or some other organization paid for?

 ◯ Yes

 ◯ No

7. Did you take any **leisure-related** air trips in 2019 ***(before COVID)*** that you personally paid for in cash? Don't include trips that someone else paid for or that you used miles for.

 ◯ Yes

 ◯ No

Programming note: Must answer yes to either Q6 or Q7.

8. In 2019 ***(before COVID)***, how did you typically travel to the airport?

 ◯ I drove myself

 ◯ I took public transit

 ◯ I had a friend or family member drive me

 ◯ I took a taxicab

 ◯ I used a ride-hailing service (such as Lyft or Uber)

 ◯ Other

Programming note: Must answer "I drove myself" or "I took a taxicab" or "I used a ride-

hailing service (such as Lyft or Uber)" to participate.

9. Do you work in the aviation industry?

   ◯ Yes

   ◯ No

Programming note: Must answer no to participate.

10. Which statement most accurately describes your student status?

   ◯ I am a full-time student

   ◯ I am a part-time student

   ◯ I am not a student

Programming note: Must not be a full-time student to participate.

11. Which of the statements best describe your current employment situation during the COVID-19 pandemic? Please select ***ALL*** that apply.

- ☐ I work full-time for pay
- ☐ I work part-time for pay
- ☐ I have two or more jobs
- ☐ I am furloughed with pay from my previous job
- ☐ I am furloughed without pay from my previous job
- ☐ I was let go from my job during the COVID-19 pandemic
- ☐ My place of employment went out of business during the COVID-19 pandemic
- ☐ I am working fewer hours during the COVID-19 pandemic
- ☐ I am working more hours during the COVID-19 pandemic
- ☐ I only do unpaid work (i.e., volunteering, unpaid internship)
- ☐ I am a homemaker or unpaid caregiver
- ☐ I am retired
- ☐ I currently do not work
- ☐ Other, please specify

Programming notes: Maximum of 10% can answer "I am a homemaker or unpaid caregiver" or "I am retired" or "I currently do not work." Minimum of 75% must work full-time for pay.

SECTION 2: Opinions About Travel

12. For each of the following statements, please check the response that best expresses your opinion of travel in 2019 ***(before COVID)*.**

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Being in a car makes me nervous if someone else is driving	○	○	○	○	○
Using a ride-hailing service, such as Lyft or Uber, is more convenient than driving	○	○	○	○	○
I like meeting new people through ride-hailing	○	○	○	○	○
I rarely consider the impact on the environment in my travel choices	○	○	○	○	○

13. Please check the response that best expresses your opinion of travel in 2019 ***(before COVID).***

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would usually rather have someone who is trustworthy do the driving	○	○	○	○	○
Whenever practical, I prefer to drive rather than take transit	○	○	○	○	○
I'm uncomfortable traveling in the same car with strangers	○	○	○	○	○
I limit my driving to help improve air quality	○	○	○	○	○

14. Please check the response that best expresses your opinion of travel in 2019 **(before COVID).**

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would tend to feel sick if I tried to read while in a moving vehicle	○	○	○	○	○
I don't mind sharing a ride with strangers if it reduces my costs	○	○	○	○	○
Even if I can use my travel time productively, I still expect to reach my destination as fast as possible	○	○	○	○	○
Please select "Agree"	○	○	○	○	○
I am fine with not owning a car, as long as I can use or rent one any time I need to	○	○	○	○	○

Programming note: Must answer "Agree" to the attention check question in order to participate.

SECTION 3: Opinions About Air Travel

15. For each of the following statements, please check the response that best expresses your opinion of air travel in 2019 ***(before COVID).***

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I like getting to and from the airport as quickly as possible, even if it costs more	○	○	○	○	○
Traveling by air makes me nervous	○	○	○	○	○
I prefer to have family or friends drop me off at the airport	○	○	○	○	○
Driving is safer overall than using a self-driving car	○	○	○	○	○

16. Please check the response that best expresses your opinion of air travel in 2019 ***(before COVID).***

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I prefer to drive and park at or near the airport	○	○	○	○	○
I am willing to spend extra time getting to and from the airport in order to save money	○	○	○	○	○
Self-driving cars are appealing to me since I would not need to park at or near the airport	○	○	○	○	○
I prefer to take a ride-hailing service such as Lyft or Uber to the airport	○	○	○	○	○

17. Please check the response that best expresses your opinion of air travel in 2019 ***(before COVID).***

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I prefer to take public transit to the airport	○	○	○	○	○
Self-driving cars are appealing to me because they allow me to use my travel time to the airport more productively	○	○	○	○	○
I like traveling by airplane	○	○	○	○	○

SECTION 4: Your Current Travel

18. How many vehicles does your household own or lease?

- ◯ None
- ◯ One
- ◯ Two
- ◯ Three or more

19. Do you own or lease a hybrid or battery-powered vehicle?

- ◯ Yes
- ◯ No

Programming note: Display Q19 only if Q18 is not equal to "None".

20. In 2019 ***(before COVID)***, how often did you use ride-hailing services, such as Lyft or Uber?

- ◯ Once a week or more often
- ◯ Two or three times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ Never

21. Which of the following explains how you have used ride-hailing services ***(before COVID)***? Please select *ALL* that apply.

- ☐ To get to or from the airport
- ☐ To get to or from work on a regular basis
- ☐ To get to or from work occasionally such as when my car is in the shop
- ☐ To go to a large event where parking may be difficult such as a ball game or concert
- ☐ To get home after a night out
- ☐ Other, please specify

Programming note: Display Q21 only if Q20 is not equal to "Never".

22. Please think of **your life in a year from now, in January 2022**: how often do you expect to do the following activities **compared to now**?

	Much less often	Somewhat less often	About the same	Somewhat more often	Much more often
Work at a regular workplace(s)	○	○	○	○	○
Telecommute and/or work from home	○	○	○	○	○
Make long-distance trips by air for work/business purposes	○	○	○	○	○
Make long-distance trips by air for leisure/personal purposes	○	○	○	○	○

23. Please think of **your life in a year from now, in January 2022:** which statement best represents your vision for where you will be living?

◯ I will be living in the same location

◯ I will be moving closer to work

◯ I will be moving further from work (e.g., to a more attractive or more spacious location)

Your Air Travel Experience

24. Have you ever flown as a passenger in the types of aircraft listed below?

	Yes	No	I'm not sure
A small plane with no overhead bins that carries ***at most 9 passengers***	◯	◯	◯
A helicopter	◯	◯	◯

25. Please check the response that best expresses your opinion.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Before COVID, I selected my flights to avoid traffic congestion on the way to or from the airport	○	○	○	○	○
Before COVID, I selected my flights on a of the week that I knew I could find parking at my departure airport	○	○	○	○	○
Before COVID, I liked to arrive to the airport early before my flight	○	○	○	○	○
Before COVID, I liked to park at my departure airport	○	○	○	○	○
Before COVID, I liked to take a ride-hailing service to my departure airport	○	○	○	○	○
Before COVID, I would have taken a ride-hailing service to my departure airport more often if I lived closer to the airport	○	○	○	○	○

26. How many roundtrips have you taken by air since COVID (or since April 1, 2020)?

- ○ None
- ○ 1
- ○ 2
- ○ 3 to 5
- ○ 6 to 10
- ○ 11 or more

27. Please check the response that best expresses your opinion.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would travel by air today	○	○	○	○	○
I would be comfortable traveling by air as soon as half of the US population were vaccinated	○	○	○	○	○
I would be comfortable traveling by air as soon as I was vaccinated	○	○	○	○	○
I am unsure of when I will feel comfortable traveling by air again	○	○	○	○	○
Before COVID, I would pay more for a nonstop flight to avoid traveling through a major hub airport	○	○	○	○	○
During COVID, I would pay more for a nonstop flight to avoid traveling through a major hub airport	○	○	○	○	○
During COVID, I would pay more to travel on an airline that blocked middle seats	○	○	○	○	○

SECTION 5: Your Most Recent Air Trip

28. Think about the last air trip you took starting from home when you flew for business when a company or organization paid for the ticket or reimbursed you for travel. When did you make this air trip?

Year

Month

Programming note: drop-down list allows respondent to select a month and year between January of 2019 and January of 2021. Question 28 appears only if individual selected yes to Q6 (business trip quota is filled first).

28B. Think about the last air trip you took starting from home when you flew for leisure for a trip that you paid for in cash (do not think about a trip that someone else paid for or that you used miles for). When did you make this air trip?

Year

Month

Programming note: drop-down list allows respondent to select a month and year between January of 2019 and January of 2021. Question 28B appears only if individual selected no to Q6 and yes to Q7 (leisure trip quota is filled last).

29. Did your trip end in an airport outside of the United States?

○ No

○ Yes

30. How long before your trip did you purchase your ticket?

○ 0 to 6 days

○ 7 to 13 days

○ 14 to 20 days

○ 21 to 30 days

○ More than 30 days

○ I don't know

31. Approximately how much was the airfare for your most recent trip by air? Do not include the cost of any tickets you might have purchased for others you traveled with.

- ○ $1 to $249
- ○ $250 to $499
- ○ $500 to $999
- ○ $1,000 to $2,499
- ○ $2,500 to $4,999
- ○ $5,000 or more
- ○ I don't know

32. What was the primary reason you flew?

- ○ Business
- ○ Attend a conference
- ○ Vacation
- ○ Visit friends or relatives
- ○ Other, please specify ____

Programming note: This is used for validation to ensure that if they answered Yes to Q6 they are actually answering the "business" trip questions.

33. How many people, associates, friends, or family members did you travel with?

- ○ I traveled alone
- ○ I traveled with 1 other person
- ○ I traveled with 2 other people
- ○ I traveled with 3 other people
- ○ I traveled with 4 other people
- ○ I traveled with 5 or more other people

34. Including yourself, how many children, young adults, and adults did you travel with?

Children aged 0-5

Children aged 6-13

Young adults aged 14-17

Adults aged 18 and older

Programming note 1: Drop-down lists are provided for 0, 1, 2 and 3 or more for each of the categories above.

Programming note 2: Display this question only if response to Q33 is not equal to "I traveled alone"

35. How many nights were you away on your trip?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7 or more

36. How many bags did you check?

- ◯ 0 bags
- ◯ 1 bag
- ◯ 2 bags
- ◯ 3 or more bags
- ◯ I don't know

Programming note: Q36 is displayed if individual traveled on business (Q6=Yes) or individual traveled on leisure alone (Q7=Yes and Q33=I traveled alone).

37. How many bags did you carry on the plane?

- ◯ 0 bags
- ◯ 1 bag
- ◯ 2 bags
- ◯ 3 or more bags
- ◯ I don't know

Programming note: Q36 is displayed if individual traveled on business (Q6=Yes) or individual traveled on leisure alone (Q7=Yes and Q33=I traveled alone).

36A. How many bags did you and the people you traveled with check?

- ◯ No bags
- ◯ 1 bag
- ◯ 2 bags
- ◯ 3 bags
- ◯ 4 bags
- ◯ 5 bags
- ◯ 6 bags
- ◯ 7 bags
- ◯ 8 or more bags
- ◯ I don't know

Programming note: Q35A is displayed if individual traveled on leisure (Q6=No and Q7=Yes) with at least one other person (Q33 is not equal to "I traveled alone").

37A. How many bags did you and the people you traveled with carry on the plane?

- ◯ No bags
- ◯ 1 bag
- ◯ 2 bags
- ◯ 3 bags
- ◯ 4 bags
- ◯ 5 bags
- ◯ 6 bags
- ◯ 7 bags
- ◯ 8 or more bags
- ◯ I don't know

Programming note: Q35A is displayed if individual traveled on leisure (Q6=No and Q7=Yes) with at least one other person (Q33 is not equal to "I traveled alone").

38. Did you pay any baggage fees?

- ◯ Yes
- ◯ No

39. What class of service did you use on your trip?

- ◯ Economy or coach
- ◯ Premium economy
- ◯ Business or first class

40. Did you receive a free upgrade to business or first class on your flight?

- ◯ Yes
- ◯ No

Programming note: Display Q40 if Q39= "Business or first class"

41. Did you receive a free upgrade to premium economy on your flight?

- ◯ Yes
- ◯ No

Programming note: Display Q41 if Q39= "Premium economy"

42. Which airport did you fly out of?

- ◯ Hartsfield-Jackson Atlanta International Airport (ATL)
- ◯ Other, please specify ______________________________

Programming note: Display Q42 if zip code in Q1 corresponds to Atlanta CSA.

42A. Which airport did you fly out of?

- ◯ San Francisco International Airport (SFO)
- ◯ Oakland International Airport (OAK)
- ◯ Norman Y. Mineta San Jose International Airport (SJC)
- ◯ Charles M. Schulz-Sonoma County Airport (STS)
- ◯ Other, please specify ______________________________

Programming note: Display Q42A if zip code in Q1 corresponds to San Francisco CSA.

42B. Which airport did you fly out of?

- ◯ Los Angeles International Airport (LAX)
- ◯ Ontario International Airport (ONT)
- ◯ John Wayne Airport (SNA), Orange County, CA
- ◯ San Bernardino International Airport (SBD)
- ◯ Hollywood Burbank Airport (BUR)
- ◯ Long Beach Airport (LGB)
- ◯ Other, please specify ______________________________

Programming note: Display Q42B if zip code in Q1 corresponds to Los Angeles CSA.

42C. Which airport did you fly out of?

- ◯ Dallas/Fort Worth International Airport (DFW)
- ◯ Dallas Love Field Airport (DAL)
- ◯ Other, please specify ______________________________

Programming note: Display Q42C if zip code in Q1 corresponds to Dallas-Ft. Worth CSA.

42D. Which airport did you fly out of?

- ◯ Boston Logan International Airport (BOS)
- ◯ Worcester Regional Airport (ORH)
- ◯ Manchester-Boston Regional Airport (MHT)
- ◯ T.F. Green Airport (PVD), Warwick, RI
- ◯ Other, please specify ______________________________

Programming note: Display Q42D if zip code in Q1 corresponds to Boston CSA.

42E. Which airport did you fly out of?

- ◯ John F. Kennedy International Airport (JFK)
- ◯ LaGuardia Airport (LGA)
- ◯ Newark Liberty International Airport (EWR)
- ◯ Other, please specify ______________________________

Programming note: Display Q42E if zip code in Q1 corresponds to New York City CSA.

42F. Which airport did you fly out of?

- ◯ O'Hare International Airport (ORD), Chicago, IL
- ◯ Midway International Airport (MDW), Chicago, IL
- ◯ Other, please specify ______________________________

Programming note: Display Q42F if zip code in Q1 corresponds to Chicago CSA

43. How did you arrive at the airport you used to start your trip?

- ◯ I drove myself
- ◯ I had a friend or family member drive me
- ◯ I took a taxicab
- ◯ I used a ride-hailing service (such as Lyft or Uber)
- ◯ I took public transit
- ◯ Other, please specify ____

44. Did you pay to park at or near the airport?

- ◯ Yes
- ◯ No

45. How much did you pay per day to park at or near the airport?

- ◯ less than $10 per day
- ◯ $10 - $19 per day
- ◯ $20 - $29 per day
- ◯ $30 - $39 per day
- ◯ $40 - $49 per day
- ◯ $50 or more per day

46. From where did you start your trip to the airport?

- ◯ My home
- ◯ Other residence
- ◯ Business or office
- ◯ College or university
- ◯ Other, please specify ____

47. What is the zip code where you started your trip to the airport?

◯ _______________

◯ I don’t know

Programming note: Validate zip codes.

48. Approximately how far was it from your starting location to the airport?

◯ Less than 10 miles

◯ 10 - 19 miles

◯ 20 - 29 miles

◯ 30 - 39 miles

◯ 40 miles or more

◯ I don't know

49. How much traffic congestion did you experience getting to the airport?

◯ Little to no congestion

◯ Minor congestion

◯ Moderate congestion

◯ Heavy congestion

50. At which airport did you end your trip?

Programming note: Display dropdown menu with FAA list of commercial airports if respondent ended their trip within the US (Q29 = “no”). Display text entry box if respondent ended their trip outside the US (Q29 = “yes”).

51. When you landed at your destination airport, how did you get to your final destination?

◯ Picked up by someone else

◯ Rental vehicle

◯ Ride-hailing service (Uber, Lyft, etc.)

◯ Taxi

◯ Limo / executive car / town car

◯ Shuttle / van

◯ Public transit (bus, rail, trolley, etc.)

◯ I don't know

◯ Other, please specify ___________________

SECTION 6: Introduction to Self-Driving Cars

In this section, we'd like to know your opinions on self-driving (or driverless) cars. Such vehicles drive themselves and control all operating and safety functions and are even able to travel without a human inside. For our purposes, we want you to imagine a future where both conventional cars and self-driving cars (that do not need humans driving them) are available.

Specifically, please assume that ...

- Driverless cars would be at least as safe as today's cars are, and they would be generally affordable.
- The car could be equipped with services such as an office, a television, or a small fridge for snacks.
- The car could be equipped with power outlets to keep your laptop and phone fully charged.
- You could send an empty self-driving car somewhere to pick up children or groceries, or to park after dropping you off at work or other locations.
- You could let a self-driving car take you places while you are sleeping.

These figures may help you imagine the possibilities:

Programming note: Images of interiors of self-driving vehicles are shown.

52. Based on the description provided so far, how appealing do you find self-driving cars?

- ◯ Very unappealing
- ◯ Somewhat unappealing
- ◯ Neutral
- ◯ Somewhat appealing
- ◯ Very appealing

53. Carefully considering your circumstances, how likely would you be to ***use*** a self-driving car for your own local travel?

- ◯ Very unlikely
- ◯ Somewhat unlikely
- ◯ Neutral
- ◯ Somewhat likely
- ◯ Very likely

54. Carefully considering your circumstances, how likely would you be to ***own*** a self-driving car for your own local travel?

- ◯ Very unlikely
- ◯ Somewhat unlikely
- ◯ Neutral
- ◯ Somewhat likely
- ◯ Very likely

55. How long after self-driving cars enter the market would you consider using one?

- ◯ In the first year of its operation
- ◯ In the second or third years of its operation
- ◯ In the fourth or fifth years of its operation
- ◯ In the sixth year of its operation or later
- ◯ Never

56. In the following questions, we will present you with potential features of self-driving cars. For each feature, we are interested in knowing how much more or less likely you would be to travel in a self-driving car, compared to a traditional car.

	Much less likely to take self-driving car	Less likely to take self-driving car	Would not affect my decision	More likely to take self-driving car	Much more likely to take self-driving car
You ***own*** the self-driving car	○	○	○	○	○
You arrange for a pick-up from a ride-hailing company (such as Lyft or Uber) and ***travel alone***	○	○	○	○	○
You arrange for a pick-up from a ride-hailing company and share with ***people you know***	○	○	○	○	○
You arrange for a pick-up from a ride-hailing company and share with ***strangers***	○	○	○	○	○

57. Please indicate how much more or less likely you would be to travel in a self-driving car, compared to a traditional car.

	Much less likely to take self-driving car	Less likely to take self-driving car	Would not affect my decision	More likely to take self-driving car	Much more likely to take self-driving car
You could use your phone to talk, text, and access the internet	○	○	○	○	○
You could do work on your laptop	○	○	○	○	○
You could sleep	○	○	○	○	○

58. About how long did it take you to commute from home to work ***before COVID-19?***

- ○ Less than 20 minutes
- ○ 21 to 30 minutes
- ○ 31 to 45 minutes
- ○ 46 to 60 minutes
- ○ 61 minutes or more
- ○ N/A

59. Would you move to a different residential location if you could regularly take a self-driving car to and from work?

- ○ I would move further from work (e.g., to a more attractive or spacious location)
- ○ I would move closer to work
- ○ I would not move

60. Would you change the number of vehicles your household owns or leases if you could regularly take a self-driving car to and from work?

- ◯ Very likely to own fewer
- ◯ Somewhat likely to own fewer
- ◯ More likely to own the same
- ◯ Somewhat likely to own more
- ◯ Very likely to own more

SECTION 7: Introduction to Air Taxis

NASA and many companies are spearheading research on urban air mobility that seeks to develop an air taxi service for cities. The aircraft:

- Are battery powered
- Carry two to four passengers
- Travel up to 50 miles within a city at cruise speeds of 150 mph
- Have efficient security checks with no lines
- In the near-term, would be flown by certified pilots on-board the aircraft
- Take off and land vertically like a helicopter
- Take off and land at locations in a city called vertiports such as the tops of buildings and parking decks
- Operate out of vertiports that would be located 0-5 miles from your home and airport locations
- Have limits on how much baggage you can bring onboard, just like a commercial aircraft
- Are much quieter than helicopters, both for the community and for the occupants of the aircraft Travel at about the altitude where traffic helicopters fly
- Do not fly in hazardous weather conditions such as thunderstorms
- Meet stringent safety requirements mandated by the U.S. Federal Aviation Administration

In this section, we ask you to imagine that you are flying in one of the new electric vertical take off and landing (or eVTOL) air taxis shown below.

Programming note: Three pictures of eVTOL aircraft are shown.

61. Were you familiar with the concept of urban air mobility prior to reading the description above?

- ◯ No
- ◯ Yes

62. Based on the description of the new aircraft provided so far, how appealing do you find this idea?

- ○ Very unappealing
- ○ Somewhat unappealing
- ○ Neither appealing nor unappealing
- ○ Somewhat appealing
- ○ Very appealing

63. How likely would you be to use such a service?

- ○ Very unlikely
- ○ Somewhat likely
- ○ Neither likely nor unlikely
- ○ Somewhat likely
- ○ Very likely

64. How long after air taxis enter the market would you consider using one?

- ○ In the first year of its operation
- ○ In the second or third years of its operation
- ○ In the fourth or fifth years of its operation
- ○ In the sixth year of its operation or later
- ○ Never

65. How much more or less likely would you be to fly in an air taxi if each feature were present?

	Much less likely	Somewhat less likely	Would not affect my decision	Somewhat more likely	Much more likely
Uses both fuel and batteries	○	○	○	○	○
Has a large parachute for the entire aircraft, so that you and the aircraft could descend safely to the ground if there were an emergency	○	○	○	○	○
Has multiple propellers for redundancy in case of failures	○	○	○	○	○

66. How appealing do you find the idea of using such a service for each of the trip purposes below?

	Very unappealing	Somewhat unappealing	Neither appealing nor unappealing	Somewhat appealing	Very unlikely
Daily commuting	○	○	○	○	○
Occasional commuting	○	○	○	○	○
Travel to a concert, sports event, or other large venue	○	○	○	○	○
Sightseeing as part of a vacation, such as over the Grand Canyon	○	○	○	○	○

67. How appealing do you find the idea of using air taxis for the following purposes associated with trips to and from the airport?

	Very unappealing	Somewhat unappealing	Neither appealing nor unappealing	Somewhat appealing	Very appealing
Travel from home or work to your local airport	○	○	○	○	○
Travel from the airport you land at to your final destination	○	○	○	○	○
Travel from your hotel or other destination to the airport for the flight home	○	○	○	○	○

68. How much more or less likely would you be to fly in an air taxi if it was operated in the following way?

	Much less likely	Somewhat less likely	Would not affect my decision	Somewhat more likely	Much more likely
Certified autonomy (no pilot on board)	○	○	○	○	○

The air taxi service may come with a ride guarantee. In the event that the eVTOL option is not available (for example due to bad weather) a ride guarantee makes sure you receive priority for taking a Lyft or Uber car. To compensate you for the inconvenience, the ride-hailing option would be discounted, and you would pay less than what the cost of an eVTOL flight would have been.

This idea is shown in the images below.

Programming note: Images of Lyft app with an eVTOL option are displayed.

69. How much more or less likely would you be to fly in an air taxi if it had a ride guarantee?

	Much less likely	Somewhat less likely	Would not affect my decision	Somewhat more likely	Much more likely
Includes a ride guarantee	○	○	○	○	○

70. Compared to clear skies, how much more or less likely would you be to take an air taxi to the airport if you checked the weather the night before you flight and learned that the following weather conditions were forecast to occur the day of your flight?

	Much less likely	Somewhat less likely	Would not affect my decision	Somewhat more likely	Much more likely
Fog	○	○	○	○	○
Light rain	○	○	○	○	○
Heavy rain	○	○	○	○	○
Lightning and thunderstorms	○	○	○	○	○

71. How frustrated would you be if the following delays happened while you were at the vertiport waiting to take the air taxi to the airport?

	Not at all frustrated — Completely frustrated 0 1 2 3 4 5 6 7 8 9 10
10-minute delay	
20-minute delay	
30-minute delay	
45-minute delay	
60-minute delay	

72. Which refund policy do you think is most appropriate for those who are using air taxis to go to the airport if they experience the following delays?

	No refund	Partial refund	Full refund
15-minute delay	○	○	○
30-minute delay	○	○	○
45-minute delay	○	○	○
60 or more-minute delay	○	○	○

73. For each of the following statements, please check the response that best expresses your opinion.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would be concerned to fly in an aircraft that takes off and lands vertically within a city with tall buildings	◯	◯	◯	◯	◯
I would find it exciting to travel in one of these eVTOL aircraft	◯	◯	◯	◯	◯
I would be concerned to travel in a battery-operated aircraft	◯	◯	◯	◯	◯
I like that these aircraft can take off and land close to my home and work locations	◯	◯	◯	◯	◯
These aircraft would cause more problems than they would solve	◯	◯	◯	◯	◯
I like the idea of battery-powered aircraft for helping the environment	◯	◯	◯	◯	◯

74. Would you move to a different residential location if you could regularly take an air taxi to and from work?

◯ I would move further form work (e.g., to a more attractive or spacious location)

◯ I would move closer to work

◯ I would not move

75. Would you change the number of vehicles your household owns or leases if you could regularly take an air taxi to and from work?

- ○ Very likely to own fewer
- ○ Somewhat likely to own fewer
- ○ Most likely to own the same
- ○ Somewhat likely to own more
- ○ Very likely to own more

SECTION 8: Mode Trade-Off Questions

We would like for you to compare three hypothetical options for traveling to the airport. The first option is to drive yourself and park at the airport using a conventional auto. The second option is to use a ride-hailing company (Lyft/Uber) to travel to the airport. The third option is for you to take an air taxi.

In all cases, we should you the door-to-door travel time to go from your home to the check-in area at the airport.

For the auto option:

- The round-trip cost includes gas and parking in the daily lot at the airport.
- It is possible that when you arrive at the airport, the daily parking lot is full, in which case you would have to park in the economy lot. For example, a probability that the daily lot is free of 90% means that you would be able to park in the daily lot 9 out of 10 times you went to the airport.

For the ride-hail option:

- The trip may be in a conventional auto with a driver or it may be in an autonomous (driverless) auto.

For the air taxi option:

- The vertiport (or location) where the air taxi departs is within 5 miles of your home.
- You can drive your car to the vertiport and park for free or have someone drop you off.
- The vertiport where the air taxi lands is located at the airport.
- A ride guarantee may be provided, meaning that if the air taxi can't fly, you get preferential access to a Lyft or Uber ride at a price that is the same or lower than the air taxi.
- The air taxi can be flown by a pilot or it can be flown autonomously (without a pilot on board).
- Air taxi operators have different on-time performance records. For example, an on-time performance of 99% means that 99 out of every 100 air taxi trips arrive at the airport on-time.

Programming note: Display the statement below for business trip purposes:

For the questions that follow, assume you are traveling ***after COVID on a four day/three-night business trip that will be reimbursed by your company or a client.***

Programming note: Display the statement below for leisure trip purposes:

*For the questions that follow, assume you are taking an air trip similar to the most recent leisure air trip you described earlier (same flights, same travel companions, same baggage, etc.) and that your trip is **after COVID for a four day/three-night trip that you are paying for yourself.***

Programming note: Display 8 trade-off questions per logic described in paper.

SECTION 9: Lifestyle and Attitudes

76. Please check the response that best expresses your opinion.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I like to wait a while rather than being the first to buy a new product	○	○	○	○	○
I like that companies can tailor products to my preferences, even if it requires me to provide personal information	○	○	○	○	○
I feel as if I need to make the most of every minute	○	○	○	○	○
For me, a lot of the fun of having something nice is showing it off	○	○	○	○	○
Having to wait can be a useful pause in a busy day	○	○	○	○	○

77. Please check the response that best expresses your opinion.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I often introduce new trends to my friends or family	○	○	○	○	○
When making a purchase, I value functionality more than the status of its brand	○	○	○	○	○
I'm concerned that technology invades my privacy too much	○	○	○	○	○
Having to wait is an annoying waste of time	○	○	○	○	○

SECTION 10: Your Use of Technology

78. How often do you use the following devices and services?

	Never or rarely	Sometimes	Often	Constantly
Basic cell phone (only calling or texting)	○	○	○	○
Smartphone	○	○	○	○
Desktop computer	○	○	○	○
Wearable technology, e.g., smart watch or Fitbit	○	○	○	○

79. How often do you post on the following?

	Never	Monthly or less	Weekly	Daily	Constantly
Facebook	○	○	○	○	○
Twitter	○	○	○	○	○
Instagram	○	○	○	○	○
LinkedIn	○	○	○	○	○
WhatsApp, WeChat, Viber, or similar	○	○	○	○	○

SECTION 11: Some Information about Yourself

80. How would you characterize the area where you live now?

- ○ Urban part of a city or region
- ○ Suburban part of a city or region
- ○ Small town
- ○ Rural area

81. What is your gender?

- ○ Male
- ○ Female
- ○ Non-binary
- ○ Prefer not to answer

82. What is the highest degree or level of school you have completed?

- ◯ Less than high school
- ◯ High school
- ◯ Some college or technical school
- ◯ Associate degree
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Doctoral degree
- ◯ Professional degree (for example: MD, DDS, DVM, LLB, JD)

83. Including yourself, how many adults ages 18 and older lived in your household as of January 1, 2020 ***(before COVID)?***

- ◯ 1 adult
- ◯ 2 adults
- ◯ 3 adults
- ◯ 4 adults
- ◯ 5 or more adults

84. How many children under the age of 18 lived in your household as of January 1, 2020 ***(before COVID)?***

- ◯ No children
- ◯ 1 child
- ◯ 2 children
- ◯ 3 children
- ◯ 4 children
- ◯ 5 or more children

85. Please select 5.

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5

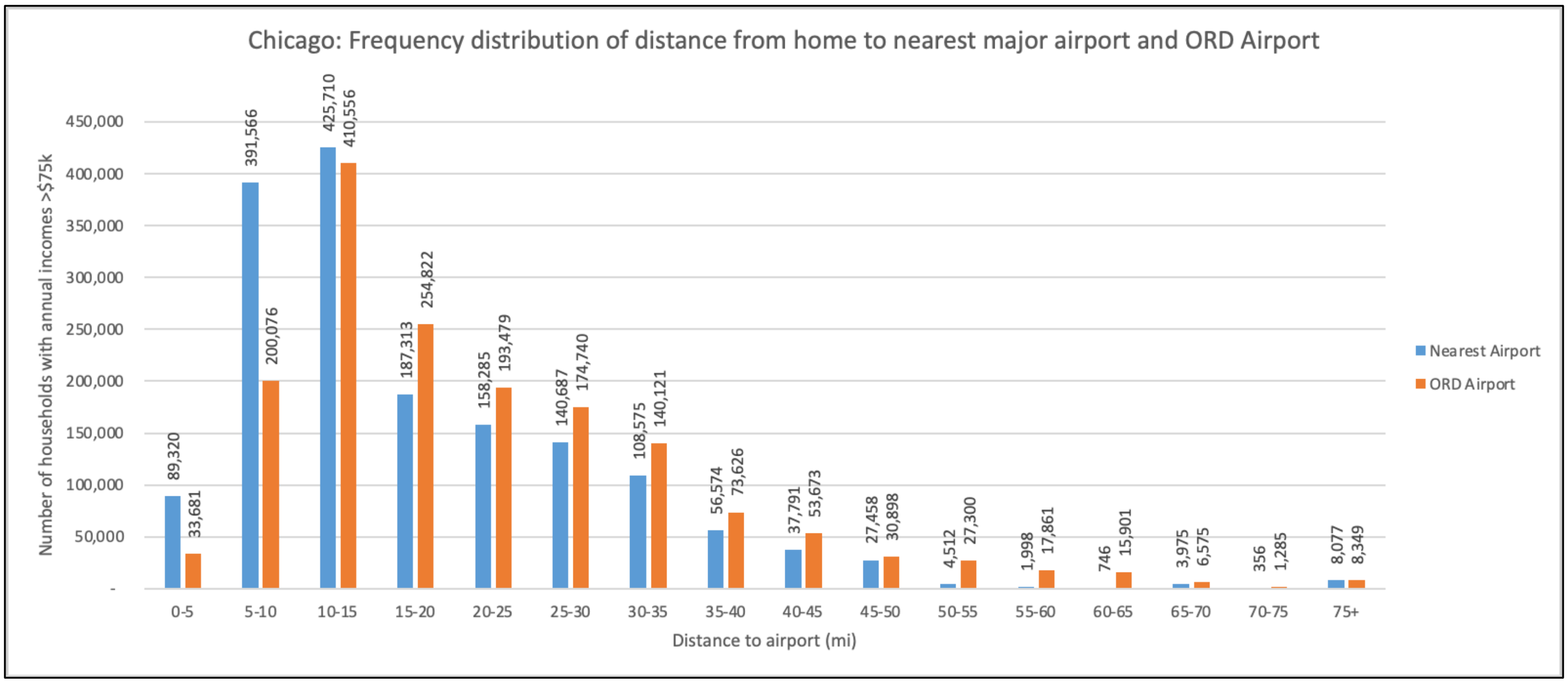
Programming note: Attention check at end of survey.

86. What is your ethnicity?

- ◯ Caucasian or White
- ◯ African or African-American or Black
- ◯ Asian or Asian-American
- ◯ Hispanic or Latino
- ◯ Other, please specify ______________________________
- ◯ Prefer not to answer

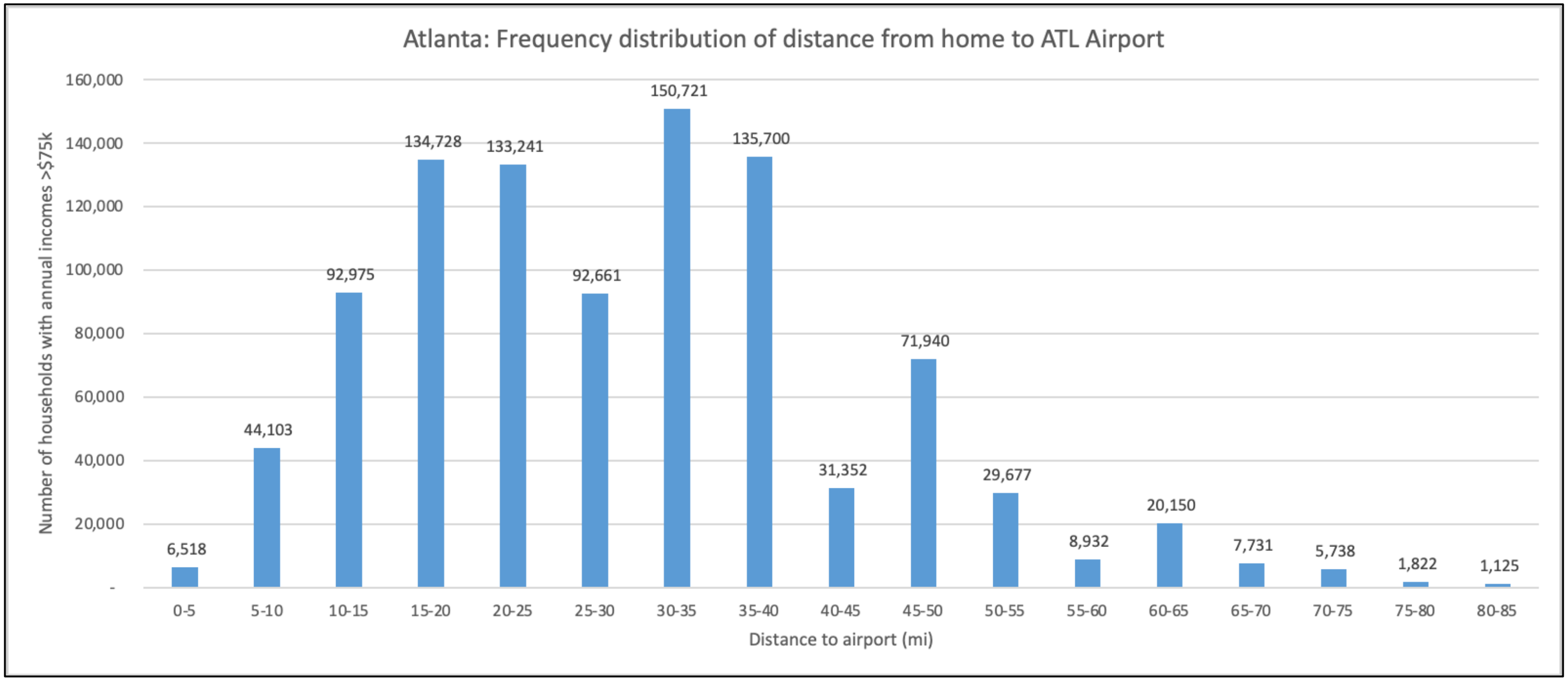
APPENDIX B. DISTRIBUTION OF DISTANCES FROM RESIDENCES WITH ANNUAL INCOMES ABOVE $75K TO THE NEAREST AIRPORT

A.1 Chicago



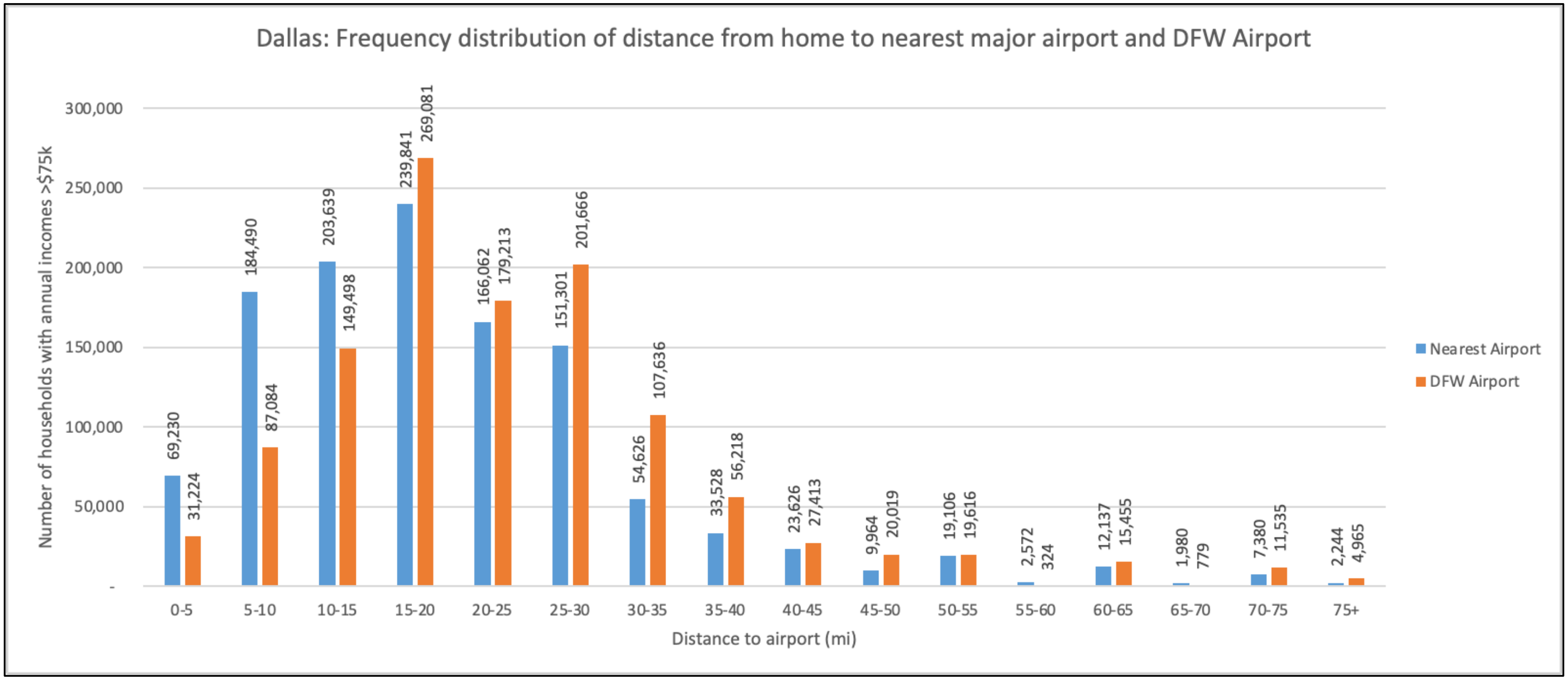
Note: Major airports considered are O’Hare International Airport (ORD) and Midway International Airport (MDW)

A.2 Atlanta



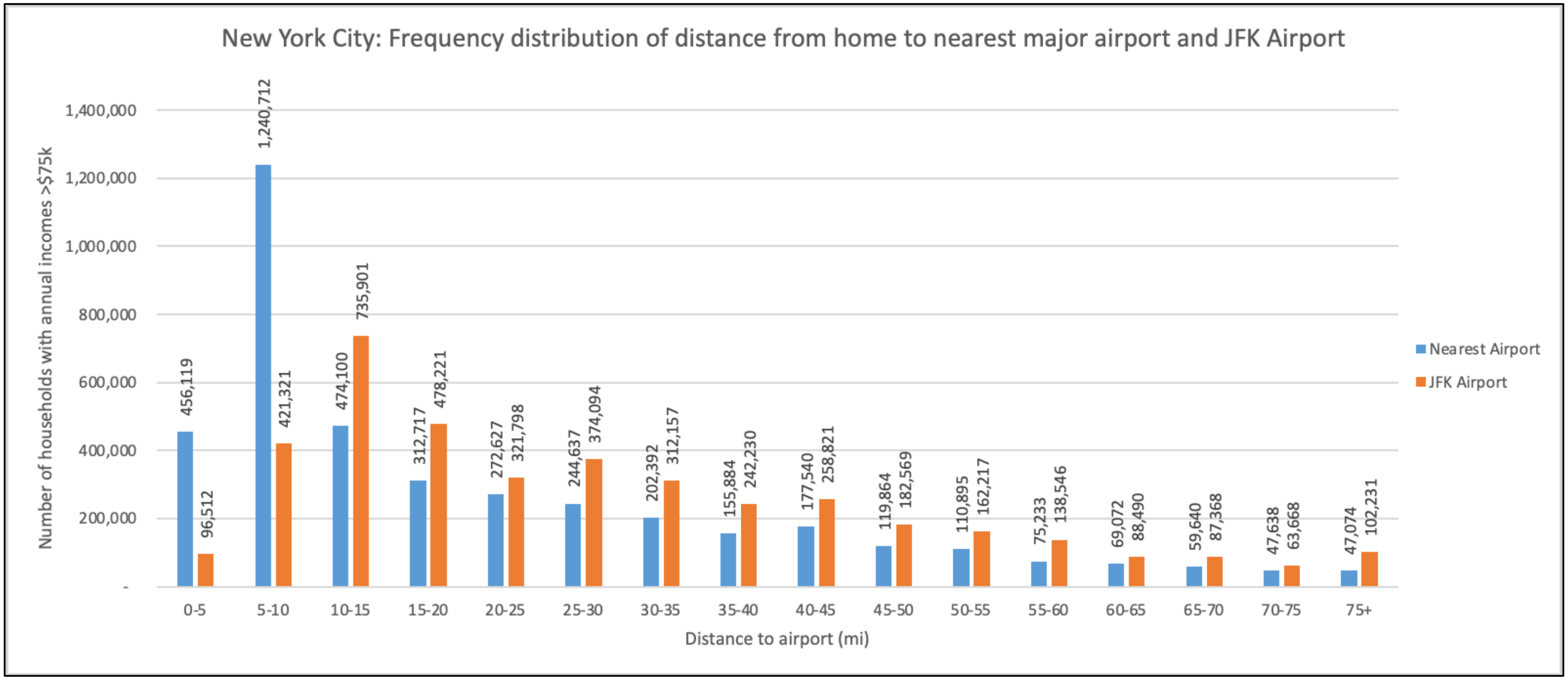
Note: Major airport considered is Hartsfield-Jackson Atlanta International Airport (ATL)

A.3 Dallas



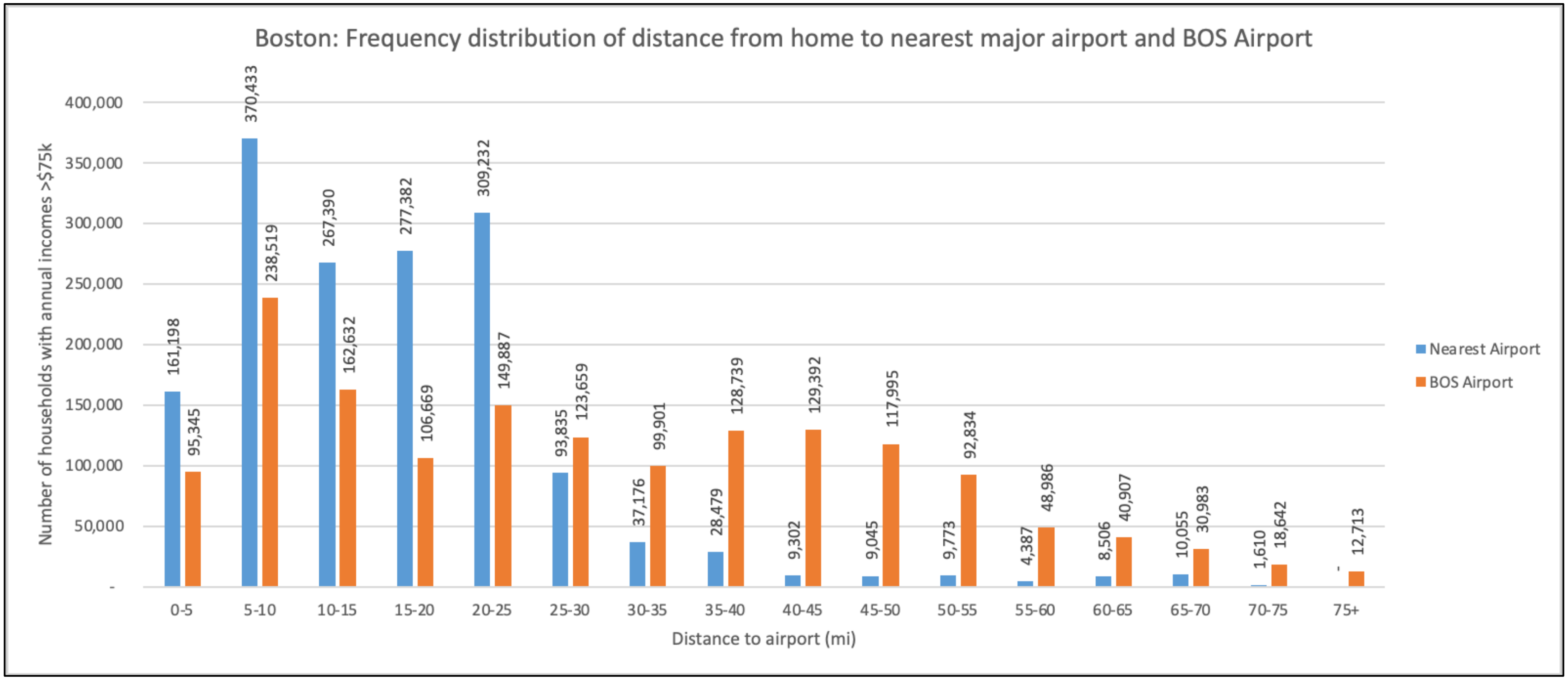
Note: Major airports considered are Dallas/Fort Worth International Airport (DFW) and Dallas Love Field Airport (DAL)

A.4 New York City



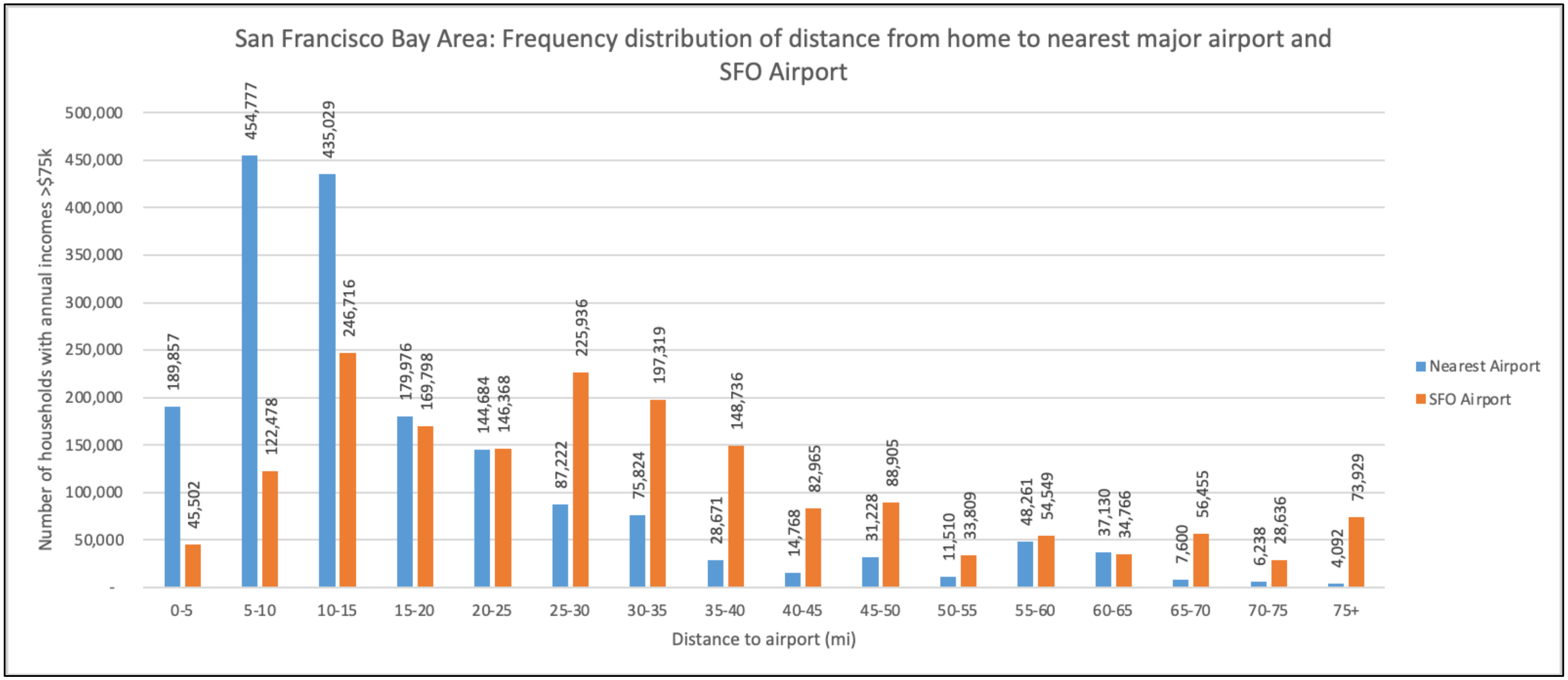
Note: Major airports considered are John F. Kennedy International Airport (JFK), LaGuardia Airport (LGA), and Newark Liberty International Airport (EWR)

A.5 Boston



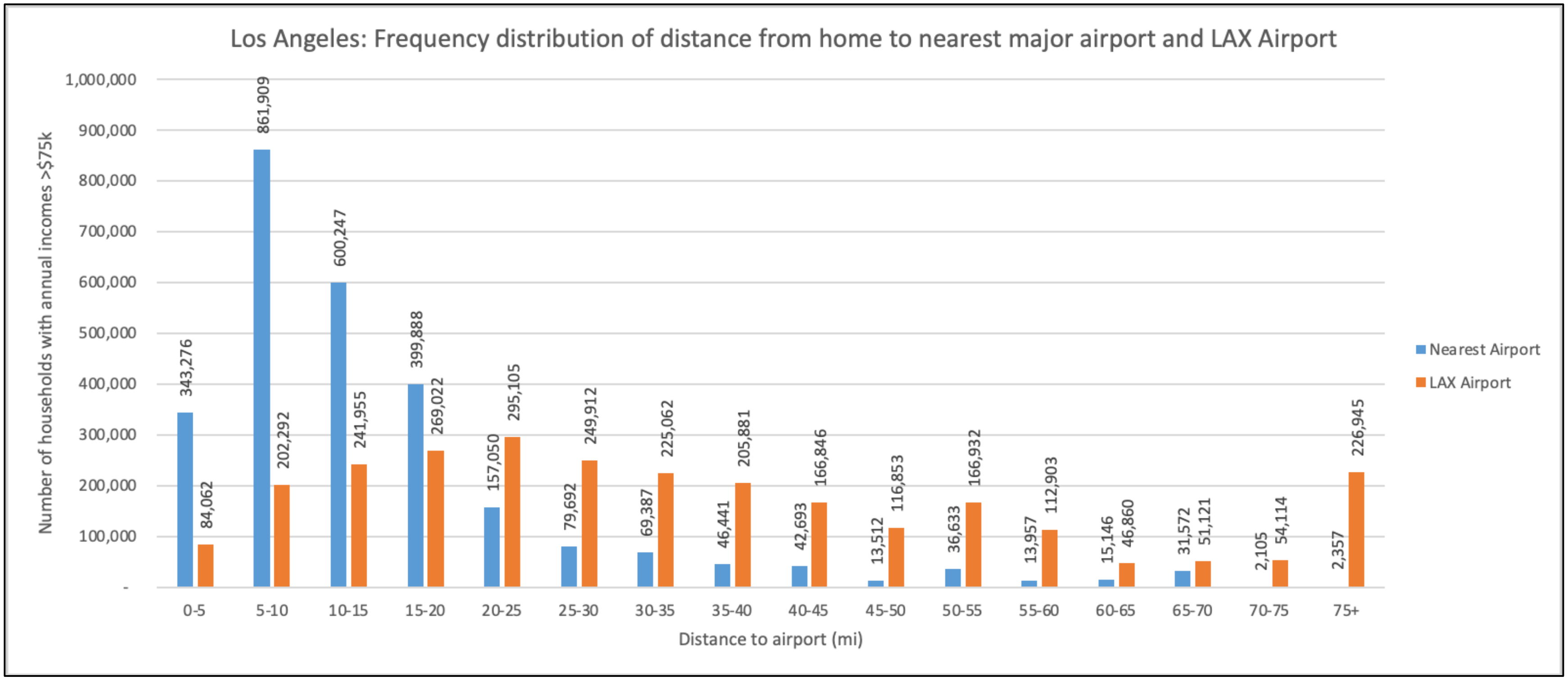
Note: Major airports considered are Boston Logan International Airport (BOS), Worcester Regional Airport (ORH), Manchester-Boston Regional Airport (MHT), and T.F. Green Airport (PVD)

A.6 San Francisco



Note: Major airports considered are San Francisco International Airport (SFO), Oakland International Airport (OAK), Norman Y. Mineta San Jose International Airport (SJC), and Charles M. Schulz-Sonoma County Airport (STS)

A.7 Los Angeles



Note: Major airports considered are Los Angeles International Airport (LAX), Ontario International Airport (ONT), John Wayne Airport (SNA), San Bernardino International Airport (SBD), Hollywood Burbank Airport (BUR), and Long Beach Airport (LGB)

APPENDIX C. NGENE OUTPUT OF TRADE-OFF QUESTION BLOCKS FOR AN EXAMPLE SCENARIO

Block	Ques	Cost Car	Time Car	Parking Availability Car	Cost Ride Hail	Time Ride Hail	Automation Ride Hail	Cost eVTOL	Time eVTOL	Automation eVTOL	On Time Performance eVTOL	Ride Guarantee eVTOL
1	1	45	25	50	15	25	1	100	25	0	80	0
1	2	45	30	90	15	25	0	75	20	1	90	1
1	3	45	30	90	20	30	0	35	15	1	95	0
1	4	40	25	90	15	25	0	75	20	1	90	0
1	5	45	35	75	20	30	1	35	10	0	99	1
1	6	40	20	99	20	30	1	125	15	0	90	0
1	7	40	20	50	20	30	1	125	10	1	80	1
1	8	45	35	75	20	30	1	35	15	0	99	1
2	1	40	20	99	20	25	0	100	25	0	80	1
2	2	45	30	90	15	25	0	75	20	0	90	0
2	3	45	30	75	15	25	0	75	20	1	95	0
2	4	40	25	90	15	25	1	75	20	1	90	0
2	5	40	35	99	15	30	0	125	10	1	99	0
2	6	40	20	99	15	25	0	125	25	0	99	1
2	7	40	25	50	15	30	0	100	10	1	80	1
2	8	40	20	99	20	25	1	125	25	1	99	1
3	1	45	30	90	15	25	1	75	20	1	95	0
3	2	45	35	75	20	30	1	35	15	0	95	1
3	3	40	35	99	20	30	0	100	10	0	80	0
3	4	40	25	50	15	25	1	100	25	0	90	1
3	5	45	35	75	20	30	0	35	15	0	95	0
3	6	40	25	50	15	30	1	125	10	0	99	0
3	7	45	25	90	15	25	1	75	20	1	90	1
3	8	45	35	75	20	30	0	35	15	0	95	1
4	1	40	35	99	15	30	1	100	10	1	80	1
4	2	40	20	50	20	25	0	125	25	1	99	0
4	3	45	30	75	20	30	1	35	15	0	99	1
4	4	45	30	90	15	25	0	75	20	1	95	0
4	5	45	30	75	20	30	1	35	15	0	95	1
4	6	45	25	50	15	25	0	100	25	1	80	0
4	7	40	20	99	20	25	1	100	25	1	80	0
4	8	40	20	50	20	30	0	125	10	0	90	1

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